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THE COMPRESSIVE STRENGTH AND TUMBLER TESTS AS CRITERIA OF THE PHYSICAL PROPERTIES OF BRIQUETS

by

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FOREWORD

It is generally recognized that suitable comparative assessment of the physical characteristics of coal briquets is not only of interest but a necessity both to the producer and consumer of this type of fuel.

Unfortunately, there are no accepted standard tests for evaluation of the various physical properties of coal agglomerates.

It is the purpose of the investigations reported here to evaluate the two tests most frequently used in North America for determining certain physical qualities of coal briquets on a comparative basis.

Section I deals with the reliability, precision and accuracy of the Komarek-Greaves Compression test for coal briquets. It presents the application of a statistical evaluation of a testing method, and as such evaluations are desirable in many engineering problems, this study may serve as an example.

Section II describes a study of the factors affecting the reliability of the ASTM:D441-45 tumbler test when applied to coal briquets, and Section III presents a correlation of tumbler with compressive strength tests, with a view to simplifying the assessment of the physical quality of briquets.

Although the three sections of this report were presented as two separate papers at the Fourth Biennial Briquetting Conference held at Estes Park, Colorado, September 1st to 3rd, inclusive, 1955, due to limited space only abridged versions of the papers were published in the Proceedings of the International Briquetting Association by the Natural Resources Research Institute of the University of Wyoming in their Information Circular No. 8. On this account and in view of the application of the statistical approach

which is increasingly being employed in most technical investigations, the papers are herewith presented in full.

It is hoped that the results of this work will be useful in aiding the establishment of acceptable standards of physical tests for coal briquets.

Acknowledgment is hereby made for the contributions of Mr. W. A. Lang, Research Council of Alberta.

GENERAL SUMMARY

In view of the lack of accepted standards for judging the physical quality of briquets, the two tests commonly used in North America were thoroughly and critically investigated.

The Komarek-Greaves tester, used for testing the compressive strength of pillow-shaped briquets, was compared under varying conditions with a standard tester developed at the Fuels Division, Department of Mines and Technical Surveys, Ottawa. The Komarek-Greaves test was found to be reliable, under certain controlled conditions as regards rate of application of pressure and temperature of the briquets. The optimum conditions were found when the pressure was increased uniformly at a minimum rate of the order of 200 r.p.m. as indicated by the rotation of the screw carrying the upper movable anvil, and when the briquets were maintained within a limited temperature range of 20° to 35°C., equivalent to ordinary summer room temperatures. Corrections to a suitable arbitrary temperature are necessary to improve the accuracy of the test. A minimum of five replicates for each test was found to give adequate precision for the average compression strength.

The ASTM:D441-45 Tumbler Test for Coal used in testing the fri-

ability of coal was found to be suitable for approximately 3-ounce, asphalt-bonded bituminous coal briquets under certain conditions and with suitable corrections when comparing briquets under different test conditions.

It appeared that three replicates were sufficient to give satisfactory precision for the average 'size stability index'. Stability increased with the temperature of testing in the range of 0 to 35°C. and with the load of briquets in the jar, and decreased with duration of tumbling, and was at a minimum for a tumbling speed of about 60 r.p.m. The test appeared to be reliable under the following optimum conditions:

constant speed of tumbling - in the order of 40 to 60 r.p.m., and

constant number of briquets - in the order of twelve (12).

The Tumbler Test was correlated with the compression-strength test, indicating that the former can be dispensed with during Winter operation but not during the higher temperatures prevailing in Summer.

GENERAL INTRODUCTION

Although the physical properties of coal briquets are of great importance in the regular operation of a briquetting plant, to the consumer, and in any study of the briquetting process, there are no accepted standards for the physical testing of coal agglomerates. Furthermore, for various reasons, the available tests are not always reliable.

Besides the test of compression to failure, which is most commonly used in North America, the other physical test most frequently employed is the evaluation of friability, that is, the tendency to breakage on handling.

Compression-Strength

The compression-strength test has often been criticized, especially

in view of indiscriminate application arising from its relative simplicity. Of the various compression-strength tests developed, the one most commonly used in North America, and which was the subject of the present study, is that developed by Komarek-Greaves and Company, Chicago, Illinois. The purpose of this study was to evaluate the reliability of the test for the control of briquetting where the briquets made are approximately of the same shape and size. Thus, the problem of comparing briquets widely different in size and shape did not occur. The investigation was confined to studying the influence of two major factors, the rate of application of load and temperature of the briquets during testing with a view to determining the optimum conditions under which most accurate repeatable results could be obtained. A statistical evaluation of the reliability, precision and accuracy of the test was made.

Tumbler Test for Friability

Most of the tests used for determining the friability, or conversely the stability, of briquets are applications of the standard tests used for coal, coke or brick. Such is the Drop-Shatter Test, usually a variation of the ASTM:D440-49 Test for Coal[1], using 25 lbs. of briquets instead of 50 lbs. of coal. Although this is regarded as a valuable test to determine the resilience properties of briquets under relatively gentle handling conditions, some adaptation of the Tumbler Test is considered preferable because it measures the same sort of property, shattering on impact, and, in addition, gives some evaluation of the susceptibility to breakage by abrasion or attrition under rather severe conditions of handling. Furthermore, the Tumbler Test is usually more convenient, especially in view of the smaller samples required. For these reasons, physical qualities of coal briquets

are often judged by some modified form of the ASTM:D441-45 Tumbler Test for Coal[1].

In view of the lack of knowledge concerning the reliability of such a test for coal briquets, it was the purpose of this study to determine the various conditions which might significantly affect the test results, in order that standards of Tumbler Testing for coal briquets could be established. It is recognized that other types of tumbler tests are useful and in some cases necessary (e.g. the large diameter rattler test for large briquets), but their application is not as wide and they were not examined in this investigation.

Section I of this report deals with the "Reliability, Precision and Accuracy of the Komarek-Greaves Compression Test for Coal Briquets". Section II is an "Evaluation of the ASTM: D441-45 Tumbler Test Applied to Coal Briquets" and Section III presents a "Correlation of the Tumbler Test and the Compression Strength Test".

SECTION I

RELIABILITY, PRECISION AND ACCURACY OF THE KOMAREK GREAVES COMPRESSION STRENGTH TEST FOR COAL BRIQUETS

INTRODUCTORY REMARKS

Mainly owing to their content of binder, briquets behave physically as a particular type of plastic material, especially when the binder is petroleum asphalt rather than coal-tar pitch or other binder. The resistance to crushing in that case is better defined by an instantaneously applied load to failure than by an increasing load applied to failure or a constant load applied for any length of time. In the case of a slowly increasing load, the briquet is gradually deformed and flattened, and cracks appear on the edges in directions parallel to the compression force. These cracks deepen and widen either with an increasing load or with time at constant load. The slower the application of the compression, the lower the load required for failure.

Because briquets at ordinary temperature, rather than being elastic or brittle, exhibit to a certain extent, pseudo-plastic characteristics similar to "creep" observed in studies of strength of materials, the French national research laboratories "Cerchar"(2) have considered that measurements of the resilience (drop-shatter tests) and cohesion (abrasion tumbler tests) may be more useful than compression-strength values to determine the quality of briquets.

However, Cerchar has also selected as criteria of the mechanical strength of briquets:

(a) instantaneous load resulting in the formation of a crack of 1 mm. width. This determination requires successive trials.

(b) flattening (expressed as a percentage of the thickness of the briquet) produced by the application of a fixed load for a given time (usually 70-80 kg. for 20 seconds).

(c) flattening produced just before failure by the application of a load, increasing at a given rate (usually 670 gr./second); or load required to obtain a given flattening (usually 2.5%) when applied with a given rate of increase (usually 350 gr./sec.).

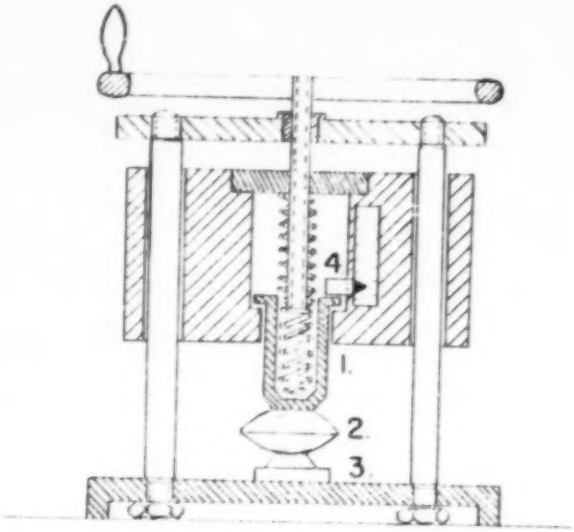
These data are obtained at Cerchar with stress-strain recording equipment. Although such criteria are desirable in laboratory studies, it was the aim of the present investigation to determine the proper procedure under which the simpler type of compression tester, such as the Komarek-Greaves tester, would give reliable results for the control of plant operations.

TEST APPARATUS

The Komarek-Greaves compression tester used in this study, and developed and manufactured by Komarek-Greaves and Company, Chicago, Illinois, is shown in Fig. 1. It consists essentially of an anvil with a flat circular surface, approximately 1 inch in diameter, supporting the briquet which is compressed by a plunger of identical shape and dimension until failure occurs. The plunger is spring-loaded and operated by a hand wheel. The compressive load exerted by the spring is indicated by means of a pointer and expressed in pounds (referred to as "K.G." or "Komarek-Greaves" units hereafter) on a gauge graduated at 25 pound intervals (the distance between consecutive graduations being approximately 1/3-inch).

Most of the briquets made in North America are ovoid or pillow-shaped, and because the surfaces of such a briquet are convex while those of the plunger and anvil are flat, the load cannot be expressed in terms of pounds per square inch. Thus readings of resistance to crushing on the

KOMAREK GREAVES TESTER



1 SPRING LOADED PLUNGER, HAND DRIVEN
2 BRIQUET
3 ANVIL
4 INDICATOR AND SCALE

F.R.L. TESTER

1 BALANCE WITH COUNTER WEIGHT AND BUCKSHOT RECEPTACLE
2 BRIQUET
3 ANVIL
4 BUCKSHOT HOPPER

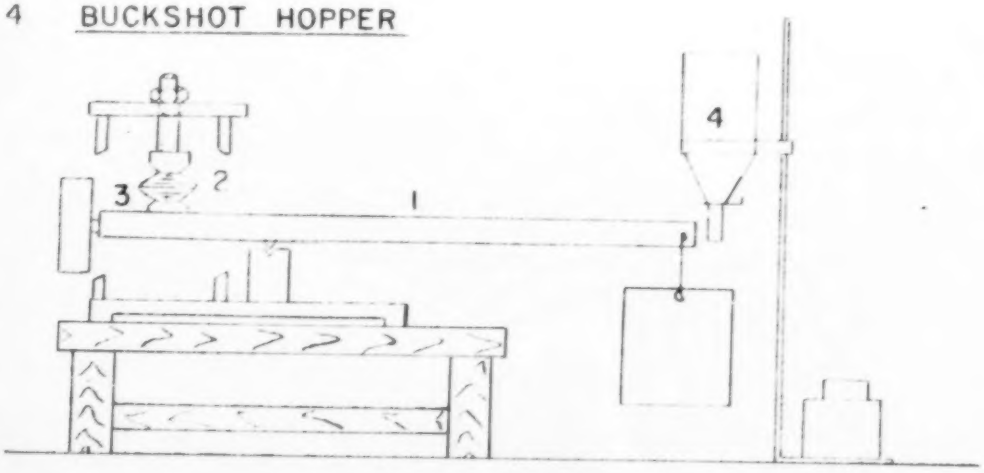


FIGURE 1.

Komarek-Greaves tester are affected by the shape and dimensions of the briquets. If accurate comparisons between briquets of different shape are required, the compressive strength must be determined on test pieces which have been filed to give parallel flat surfaces (Parry and Goodman[3]) or by cutting the briquets into cylindrical samples of standard dimensions, or by capping the ends of the briquets with a thermoplastic compound (e.g. "Plasticarve") and cutting them into cylinders of standard dimensions (Boley and Rice[4]).

However, as indicated by Strong, Swartzman and Burroughs[5], the Komarek-Greaves compressive-strength test is better adapted to testing for the maintenance of a standard quality in any one plant than for comparing briquets from different plants.

As the purpose of this study was to evaluate the reliability of the test most frequently used in North American plants for the control of briquetting, that is, the Komarek-Greaves test as used on briquets having approximately the same shape and size, the problem of comparing briquets widely different in size and shape did not occur.

TEST PROCEDURE AND RESULTS

Although in comparing briquets it is usually considered that they should be tested at similar temperatures and by operating the Komarek-Greaves tester at the same speed, in practice, to-date, seldom has any effort been made to attain these conditions or to ascertain the influence of these factors on test results.

As the compression-strength test is destructive, individual briquets cannot be tested more than once, and therefore the tests were conducted on one large, homogeneous sample of briquets which were collected

simultaneously from a commercial roll press (30 tons/hour) in order to reduce to a minimum the possible variations of strength between individual briquets. These typical briquets, made of bituminous coal and petroleum asphalt, were kept in storage for several days before the tests were done.

In order to supply the data required, tests were conducted at different temperatures and varying rates of application of pressure. This latter was effected by varying the rate at which the hand wheel, controlling the movement of the spring-loaded plunger, was rotated. This is shown in Table I under the heading "R.P.M.".

The complete data on the tests conducted at 21°C. and 32°C. and at varying rates of pressure application from about 60 r.p.m. to 215 r.p.m. are presented in twelve subgroups in Table I.

TABLE I

Compression Strength Tests on the Komarek-Greaves Tester

GROUP I						
Testing Temperature T_1 = 21°C.						
Subgroup No.	Test No.	R.P.M.	Time to failure seconds	Strength - K.G. Units		
				Single observation	Average	Standard deviation
J	1	67	21.6	220	197	17.2
	2	48	27.4	200		
	3	54	21.2	180		
	4	56	21.6	180		
	5	60	22.0	205		
A	6	69	18.2	190	203	15.2
	7	70	19.8	215		
	8	74	18.6	220		
	9	83	16.0	205		
	10	77	15.6	185		
D	11	106	13.	205	215	10
	12	107	11.8	210		
	13	104	12.7	230		
	14	104	13.8	220		
	15	121	11.4	210		
G	16	147	9	215	222	4.5
	17	142	9.2	225		
	18	138	10.0	220		
	19	150	9.2	225		
	20	144	9.2	225		
B	21	185	7.8	225	222	5.6
	22	180	8.0	215		
	23	180	8.0	220		
	24	178	8.1	220		
	25	190	7.6	230		
F	26	214	7.0	225	224	2.2
	27	214	7.0	225		
	28	218	6.3	220		
	29	216	6.4	(210)[1]		
	30	218	6.6	225		

[1] As this value does not belong, statistically, to its subgroup, it was replaced by the subgroup average.

TABLE I (cont'd)

Compression Strength Tests on the Komarek-Greaves Tester

GROUP II						
Testing Temperature T_2 - 32°C.						
Subgroup No.	Test No.	R.P.M.	Time to failure seconds	Strength - K.G. Units		
				Single observation	Average	Standard deviation
E	31	60	15	125	119	10.8
	32	53	16	105		
	33	58	14.4	130		
	34	56	16.0	125		
	35	59	14.2	110		
K	36	65	14.8	135	124	7.4
	37	70	12.8	115		
	38	73	12.4	120		
	39	73	13.2	125		
	40	73	12.4	125		
L	41	89	10.8	135	126	8.2
	42	87	10.4	120		
	43	79	11.4	115		
	44	84	11.4	130		
	45	80	12.0	130		
C	46	119	9.6	(175)[2]	148	5.6
	47	123	8.8	155		
	48	120	9.0	145		
	49	116	8.8	150		
	50	119	8.6	140		
H	51	163	7.0	155	154	2.2
	52	154	7.0	155		
	53	146	7.0	155		
	54	146	7.4	155		
	55	142	8.0	150		
I	56	210	6.0	180	177	2.7
	57	210	6.0	180		
	58	210	6.0	175		
	59	224	5.5	175		
	60	210	6.0	175		

[2] As this value does not belong, statistically, to its subgroup, it was replaced by the subgroup average.

DISCUSSION OF RESULTS

Reliability of the Test

The reliability of the test was studied according to methods recently presented at the American Society for Testing Materials[6,7].

A test method is not reliable if the results given by a series of tests (on the same specimen or on a number of similar specimens from a homogeneous sample) are erratic and unpredictable, due to lack of control over the various factors contributing to variability of the test results. However, even after all assignable causes of variability are well controlled, the test results still show fluctuations, but evaluation of the precision and the accuracy of the test method is possible if the fluctuations behave in a statistically predictable manner.

One of the simplest statistical techniques to determine whether a test method is reliable or not is the control chart, such as shown on Fig. 2, where the data obtained from sixty determinations of compression-strength with the Komarek-Greaves tester are used.

The tests were made in 12 sub-groups, A to L inclusive, of 5 tests each, and within each sub-group the five tests were made consecutively and under practically identical conditions. The lower graph of Fig. 2 shows the 12 sub-groups of 60 individual results, x. The center graph shows the range, R (difference between the lowest and highest of the 5 results within each sub-group). The upper graph shows the 12 averages, $\bar{x}$, of each sub-group. On each graph, the center value and the control limits are shown as determined according to A.S.T.M. standards for control charts. None of the averages or ranges for the sub-groups should fluctuate outside the control limits if the factors affecting the variability of replicate determinations were uniformly controlled among the various sub-groups. However, because of the wide

Control Charts for Individual Tests x, Ranges R,

and Averages $\bar{x}$ of the 12 Subgroups

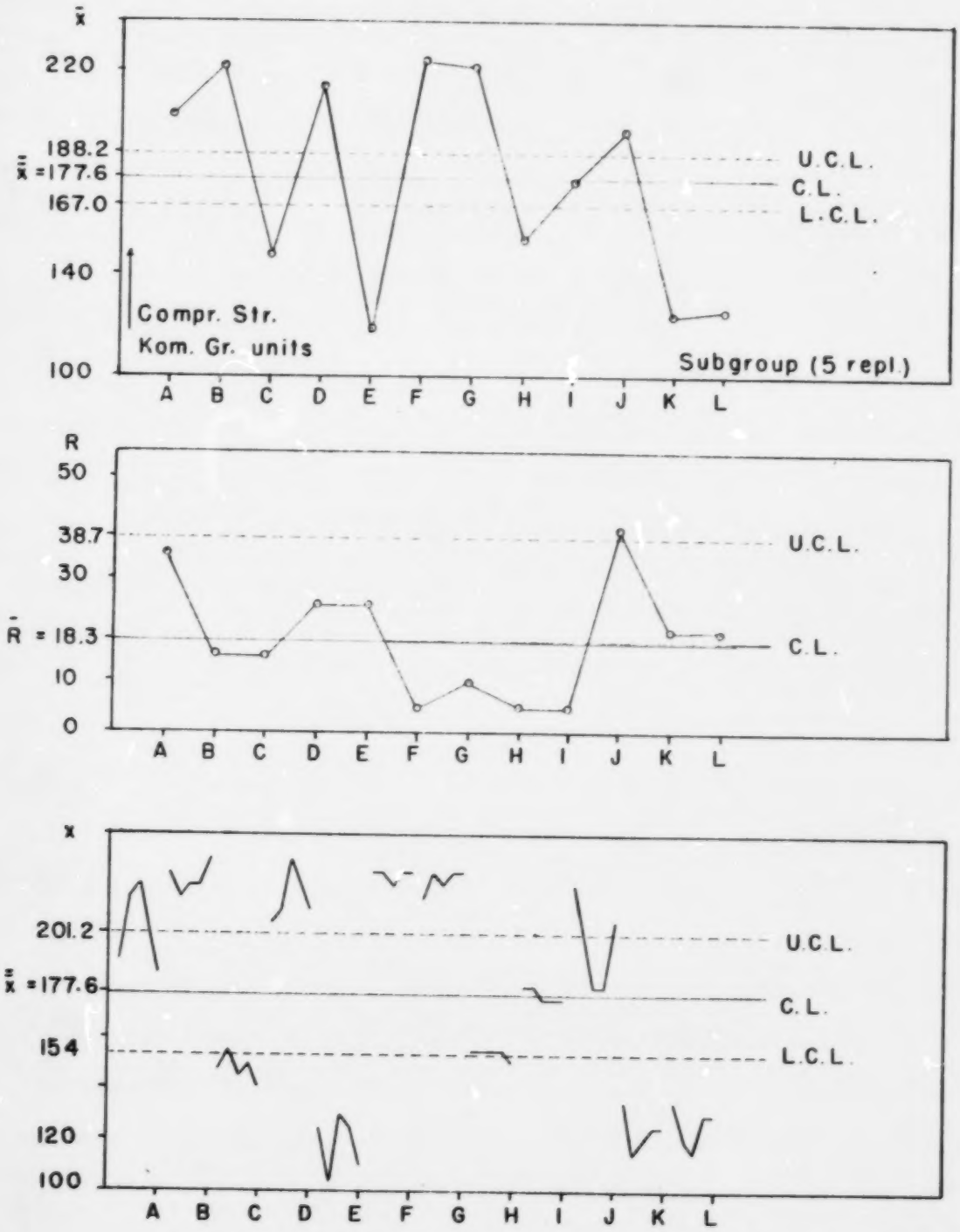


FIG. 2.- CONTROL CHARTS FOR KOMAREK-GREAVES TESTS

Legend: Central Lines, C.L. ———
Upper Control Limit U.C.L. - - - - - -
Lower Control Limit L.C.L. - - - - - -

fluctuations, it is apparent that some assignable causes of variability were not under control.

Owing to the pseudo-plastic nature of briquets, their temperature during the test is an influencing factor on the strength, and because of the phenomenon of "creep" introducing the time element in the behaviour under compression, the data were rearranged in two groups of 6 sub-groups each, namely, J, A, D, G, B, F at a temperature of 21°C. and E, K, L, C, H, I at a temperature of 32°C. The sub-groups in each group were rearranged in order of increasing speeds of operation of the Komarek-Greaves tester, ranging from 50 to 220 r.p.m. The results are plotted in Fig. 3.

For each group of 30 tests at the same temperature, control charts can be plotted, showing that the test method is still unreliable, although to a lesser extent than previously. However, for each of the two half groups of the tests made at high speeds, control charts can be established, showing that the test method is reliable when the tests are made at constant temperature and beyond a certain speed (within the temperature range 20° to 35°C. and beyond approximately 150 r.p.m., in the case of the briquets used for this study).

In order to illustrate these results, all the data given in Table I are plotted on Fig. 4, showing individual values and averages of strength as a function of the speed of the tester and the temperature of testing. Statistically, Test No. 29 (Table I) can be eliminated (its deviation from the average of its sub-group is greater than three times the standard deviation of that sub-group). The same applies to Test No. 46. The variation in dispersion of each sub-group of 5 replicates is clearly shown in Fig. 4, indicating that, as the speed increases, the dispersion of results decreases and that beyond 150 r.p.m. the variance in results is relatively low.

Control Charts of Fig.2 with the Subgroups rearranged in Two Groups (J-A-D-G-B-F) at 21°C. and (E-K-L-C-H-I) at 32°C., and in order of increasing Speeds of Testing within each Group.

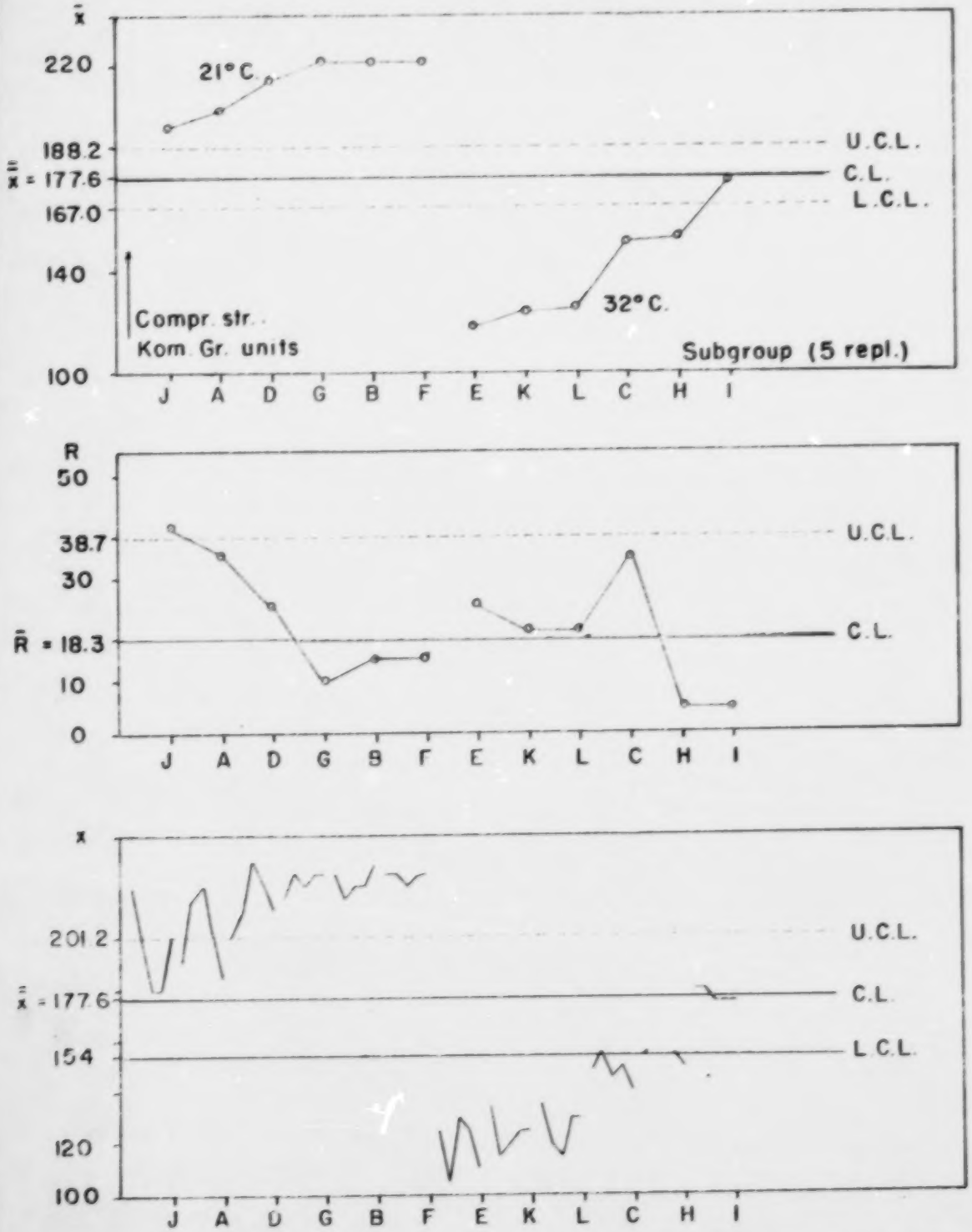


FIG.3- CONTROL CHARTS FOR KOMAREK-GREAVES TESTS

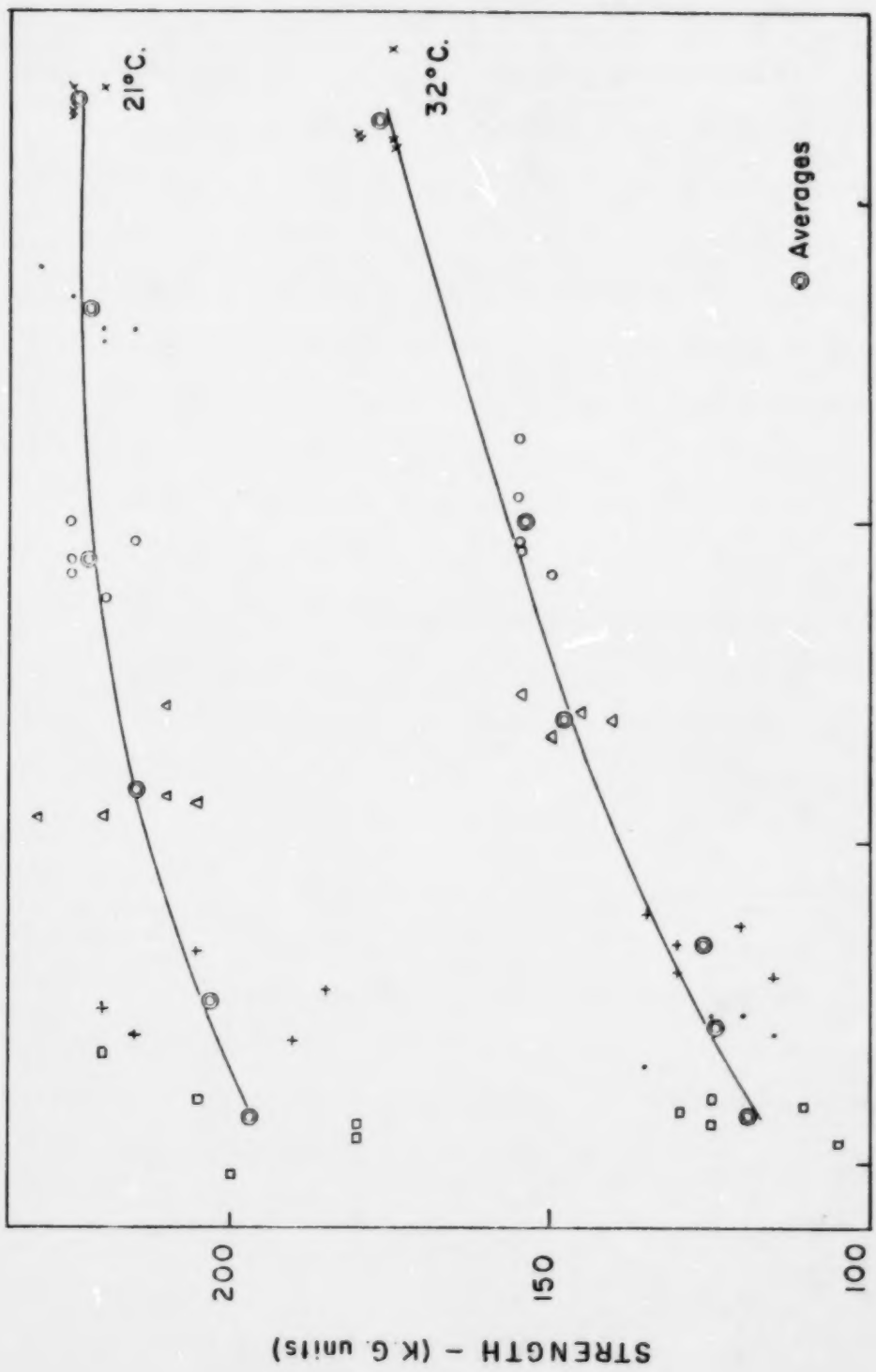


FIG. 4 – KOMAREK – GREAVES STRENGTH TESTS.

Precision

Under well-controlled conditions ensuring reliability of the test (i.e. constant temperature and adequately high speed), the precision of the method is a measure of its variability during repeated tests on the same specimen or a series of specimens from a homogeneous sample.

The best method of expressing the precision of a test method is by calculating the standard deviation of individual results. In this case, the standard deviation has been calculated as shown in Table I, which gives the speed, strength, and time to failure in each case and also the average value of strength and the standard deviation for each sub-group.

This study has dealt only with precision of "repeatability", which is the case when all tests are made under identical conditions (by the same operator, with the same testing equipment, etc.). In some cases, it may be of interest to determine the precision of "reproducibility" when the tests are made by different operators, using different testing machines of the same type.

When applying the Komarek-Greaves tester on the particular type of briquets used in this study, at a constant temperature within the range of 21° to 32°C. and at a constant speed between 150 and 220 r.p.m., the average standard deviation of a single observation is $s = 3.7$ K.G. units. The standard deviation of an average of 5 observations is $\bar{s} = \frac{3.7}{\sqrt{5}} = 1.7$ K.G. units. The p r e c i s i o n of the average $\bar{x}$ of N test results x (with a 95% probability) is:

$$a = 1.96 . \frac{s}{\sqrt{N}} = 1.96 . \frac{3.7}{\sqrt{5}} = 3.3 \text{ K.G. units}$$

This precision, obtained with 5 replicates, is acceptable in practice in view of the errors of sampling, reading the indicator gauge, etc.

The average $\bar{x}$ may be made more precise by testing more replicates. The minimum number n of tests required to obtain the average $\bar{x}$ of n test results x within a certain precision range $\pm a$ (with a 95% probability) is such that:

$$n = \left(\frac{1.96 \cdot s}{a}\right)^2$$

For example, a precision range of ± 2 K.G. units with a 95% probability requires, in this case, a minimum of approximately 14 replicates.

Accuracy

When a test method is reliable, its accuracy is an expression of how close it is to giving the "true" value of the characteristic which is being measured.

In the case of the compression-strength test, if the "true" value were known or could be computed from theory, the "absolute" accuracy could be expressed as the deviation of test results from the true value. But since there is no "true" value of resistance to crushing (this is generally so for most physical tests), the accuracy can be determined by comparison of the test results obtained with the Komarek-Greaves tester with arbitrarily accepted standards. These standards would be the test values given by suitably designed and standardized test equipment of a type which can be considered as less liable to bias, systematic errors, unreliability, and imprecision.

Various Tension-Compression testing machines of the hydraulic or mechanical types could be used to establish arbitrary standards for the evaluation of the accuracy of the Komarek-Greaves test. However, an earlier investigation had shown that, under specific conditions, a very simple tester developed by the Fuel Research Laboratory of the Department of Mines and Technical Surveys, Ottawa, was suitable for this purpose (see Fig. 1).

This F.R.L. Compression-Strength Tester[8,9] exerts a compression of the briquet between two flat circular surfaces of approximately 1" diameter. It operates on the lever principle with the fulcrum between the briquet and a variable weight which is adjusted as desired and measured on a balance. The ratio of the length of the lever from weight to fulcrum and briquet to fulcrum is 4 to 1; therefore, the weights (in excess of the dead weight required for equilibrium of the lever) must be multiplied by 4. If the F.R.L. tester is gradually loaded, the phenomenon of "creep" mentioned above may be very important even when always starting with a negligible load, because the rate of increase of the load (lead shot falling into a receptacle) is rather slow and the total duration of the compression varies widely with the ultimate strength of the briquet. Then, the dispersion of the results is wider with increasing durations of compression as in the case of the Komarek-Greaves tester. The effects of "creep" may be studied by determining the times required for failure with various instantaneously applied loads, as shown in Fig. 5, where compression-strength results for a large number of briquets (from the same sample as previously used on the Komarek-Greaves tester) conducted at temperatures of 21°C. and 32°C., are plotted.

TABLE II

Time to Failure for Instantaneously Applied Loads on the F.R.L. Compression Tester

Load (Weight x 4) lbs.	56	66	76	86	96	116	136	156	176
Briquet Temperature, °C.	22	23	20.5	22	22	23	23	23	21
Time to Failure in secs.	+1800	1151	387	120	167	86	34	38	21
	+1800	606	142	104	103	38	26	19	18
	+1800	892	143	137	159	54	37	36	11
	+1800	1216	170	211	137	86	37	14	26
	3480	--	--	--	--	--	--	--	22
Average Time, secs.	+1800	878	204	183	139	75	35	26	19.6
Average Time Corrected to 21°C.	--	1035	201	191	151	89	41	31	19.6
Number of Tests	5	10	25	25	25	25	25	10	5
Standard Deviation of Single Observation	--	302	70	107	28	23	14	9.1	5.6
Standard Deviation of Average	--	95	14	21	5.6	4.6	2.8	2.9	2.5

Load (Weight x 4) lbs.	196	204	212	220	228	236	240	244
Briquet Temperature, °C.	21	22	22	22	21	21	21	21
Time to Failure in secs.	9	9.2	6.5	5.0	2.2	0	0	1.6
	7	7.4	5.0	2.2	3.0	2	0	1.0
	15	9.4	8.0	2.9	2.6	4	1.5	0
	7	10.0	6.2	5.4	4.2	2	5.4	0
	11	10.0	7.0	6.2	1.8	2	1.6	0
Average Time, secs.	9.8	9.2	6.5	4.3	2.8	2.0	1.7	0.5
Average Time Corrected to 21°C.	9.8	9.9	7.2	4.9	2.8	2.0	1.7	0.5
Number of Tests	5	5	5	5	5	5	5	5
Standard Deviation of Single Observation	3.3	11.7	1.1	1.7	2.8	1.4	2.2	0.7
Standard Deviation of Average	1.48	5.2	0.49	0.76	1.26	0.63	0.98	0.31

TABLE II (Cont'd)

Time to Failure for Instantaneously Applied Loads on the F.P.L. Compression Tester

Load (Weight x 4) lbs.	56	66	76	96	116	126	136	156
Briquet Temperature, °C.	30	30	30	30	31	31	31	32.5
Time to Failure in secs.	+1800	459	153	39	14	18	8	6.0
	+1800	195	127	56	19	14	13	6.8
	+1800	292	180	49	22	13	12	6.0
	+1800	251	147	55	17	21	10	8.0
	+1800	437	162	31	22	9	11	5.6
Average Time, secs.	+1800	327	154	46	19	15	10.8	6.5
Average Time Corrected to 32°C.	--	170	143	23	12	10	7.8	8.2
Number of Tests	5	5	5	5	5	5	5	5
Standard Deviation of Single Observation	--	116	19	10.7	6.8	4.6	1.9	0.95
Standard Deviation of Average	--	54	8.5	4.8	3.0	2.1	0.85	0.42

Load (Weight x 4) lbs.	164	172	180	188	196	208	216
Briquet Temperature, °C.	32.5	32.5	32	32	32	31	31
Time to Failure in secs.	6.4	3.6	3.6	2.4	2.4	1.5	1.0
	5.8	4.8	3.0	2.6	2.4	1.4	0.9
	7.6	4.8	4.2	3.4	3.0	1.0	1.7
	4.4	5.2	4.4	3.0	3.0	1.0	1.3
	5.0	5.6	3.0	4.0	2.6	1.1	0.8
Average Time, secs.	5.8	4.8	3.6	3.1	2.7	1.2	1.1
Average Time Corrected to 32°C.	6.1	5.5	3.6	3.1	2.7	0.5	0.5
Number of Tests	5	5	5	5	5	5	5
Standard Deviation of Single Observation	1.2	0.74	0.65	0.62	0.3	0.22	0.37
Standard Deviation of Average	0.54	0.33	0.29	0.28	0.13	0.10	0.17

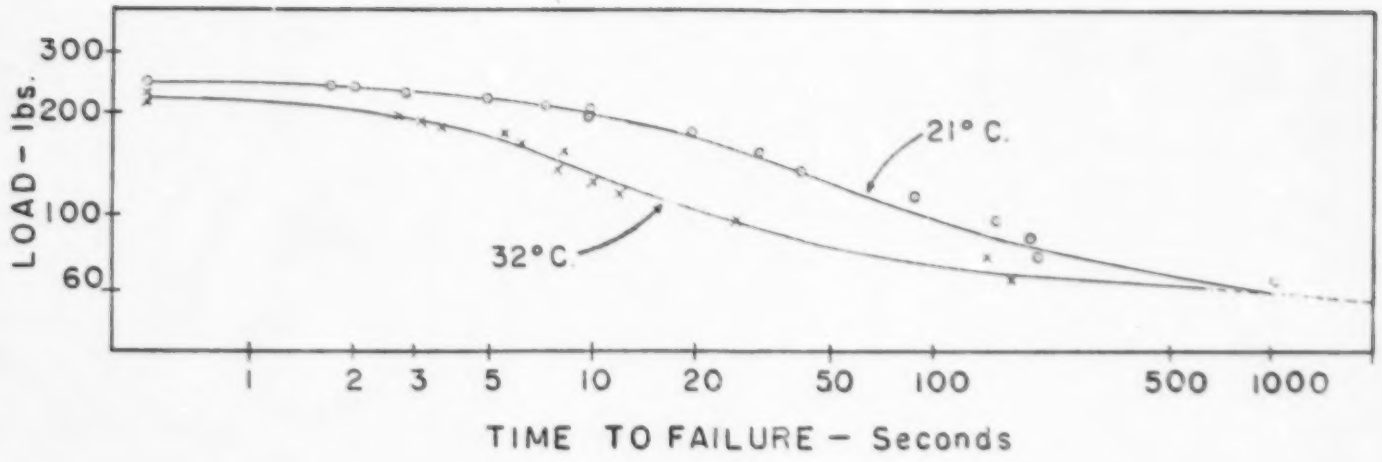


FIG. 5. - F.R.L. COMPRESSION TESTER

The data used is shown in Table II which gives the average times to failure and the standard deviations with the corresponding number of briquets tested for each constant load applied.

In view of the low dispersion of test results, the F.R.L. test is considered reliable on the type of briquets under consideration, when used at constant temperature within the range 21° to 32°C. and with a constant load providing the time of compression does not exceed approximately 5 seconds (the isotherm curves are then almost level). The precision of the F.R.L. test is best when the duration of loading is shortest. These conditions can be assumed when arbitrarily adopting the instantaneous failure value on the F.R.L. test as the standard compression strength at a given temperature for evaluating the accuracy of the Komarek-Greaves tester by comparison. This is justified because, in the F.R.L. test, although the precision is not excellent, there is neither the error of reading of graduations nor the error of calibration of the spring which may occur in the Komarek-Greaves test.

One of the best ways to evaluate the accuracy of a test method by comparison with standard results is the correlation of values obtained under the same conditions. On Fig. 6 are plotted Komarek-Greaves test results at two speeds, 120 r.p.m. and 215 r.p.m. respectively, in ordinate with the F.R.L. tester instantaneous failure value corresponding to the same temperature in abscissa (points A and B at 32°C. and C and D at 21°C.). Curve AC shows the correlation at higher speed (215 r.p.m.) and curve BD shows the correlation at lower speed (120 r.p.m.), both speeds corresponding to acceptable reliability of the Komarek-Greaves test. In each of the four cases, the average of 5 replicates is plotted with the corresponding standard deviation limits for the Komarek-Greaves tests in ordinate. The data are

given in Table III.

If accurate, a test method should give on this correlation graph a straight line (such as line EE) with an intercept of zero and a slope of one. The closer the correlation curve is to line EE, the better is the accuracy of the test method. Fig. 6 shows that the Komarek-Greaves test is more accurate at the higher speed and at the lower temperature, with the standards adopted and under controlled conditions.

TABLE III

Data for Correlation of The Komarek-Greaves Strength Tester with The F. R. L. Tester (see Fig. 6)

	High Temperature 32°C.		Low Temperature 21°C.	
Standard: Loads producing immediate failure on the F. R. L. Tester in lbs.	208 208 216 216 216		228 240 240 244 244	
Average Load	212.8		239.2	
Correlation Points on Fig. 6	B	A	D	C
Corresponding Values on the Komarek-Greaves Tester in Komarek-Greaves Units	Speed		Speed	
	120 r.p.m.	215 r.p.m.	120 r.p.m.	215 r.p.m.
	147	176	218	224
Standard Deviation (approximate)	5.6	2.7	10	2.2
Coefficient of variation between both Testers in %	25.8	13.4	6.6	4.7

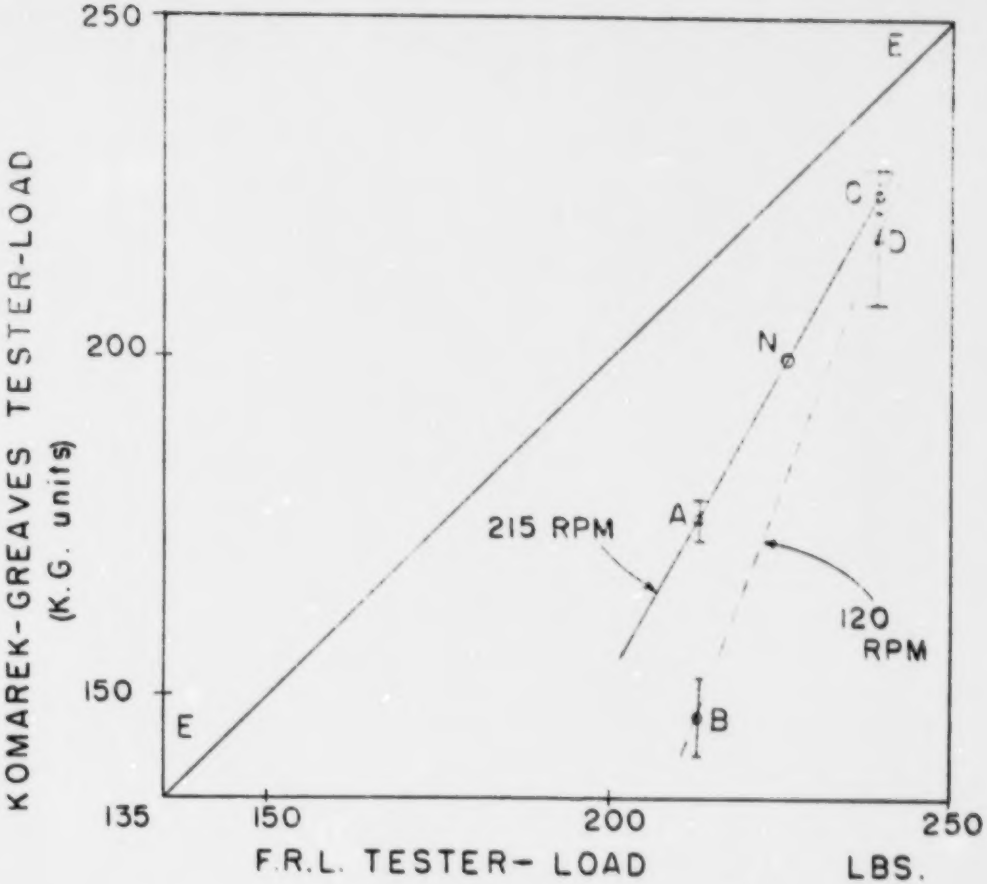


FIG. 6.- CORRELATION OF THE KOMAREK-GREAVES STRENGTH TESTER WITH THE F.R.L. TESTER. EE is the line of perfect correlation.

The difference in the zero intercept is a systematic inaccuracy analogous to the difference between the 0°C. and the 32°F. in temperature scales, and may be accounted for, within a limited range, by a constant correction of the test results. In this case, the Komarek-Greaves values could be increased by approximately 25 units (which is the difference between Komarek-Greaves and F.R.L. high-speed values at the median level for the range of temperatures - point N in Fig. 6).

The difference in the slope of the correlation curve is a variable inaccuracy analogous to the 5/9 ratio between centigrade and fahrenheit degrees, and may also be accounted for, within a limited range, by a constant correction factor. In this case, any deviation of the Komarek-Greaves value from the arbitrary value of 200 (median level for the range of temperatures - point N in Fig. 6) could be multiplied by 2/3.

If the correlation curves differ statistically from straight lines, i.e. by values exceeding standard deviations or multiples thereof according to the probability level desired, there are other causes of inaccuracy depending upon the level of the compression strength under test. These may be defects of the tester spring or peculiar characteristics of the briquet binder. When the correlation curves are determined from a larger number of points (at various temperatures), and are not too different from straight lines, their equations may be of the form:

$$y - \bar{y} = b\,(x - \bar{x})$$

where x and y are individual values and $\bar{x}$ and $\bar{y}$ are average values of respectively F.R.L. tests (x) and Komarek-Greaves tests (y), and b is the regression coefficient[10]:

$$b = \frac{\sum(x - \bar{x})\,(y - \bar{y})}{\sum(x - \bar{x})^2}$$

Then the correlation coefficient is: $r = b\sqrt{\left[\frac{\sum(x - \bar{x})^2}{\sum(y - \bar{y})^2}\right]}$ and the closer it is to one, the more legitimate is the assimilation of the correlation curve to a straight line.

The correlation curves could also be determined by testing simultaneously on the Komarek-Greaves tester and on the F.R.L. tester various samples of briquets of different quality and plotting the two values obtained for each sample, but this would not show the effect of temperature and speed of rotation of the Komarek-Greaves tester as was shown here.

Temperature Susceptibility

Since it is usually difficult to control the temperature of briquets when they are tested, the influence of temperature was the object of a special study. Acknowledgment is hereby made of Mr. W. A. Lang's contribution in this regard(11).

On Fig. 7 are plotted averages of the compression strength values of 5 replicates on the Komarek-Greaves tester under varying conditions(12). All the briquets were made in the same plant under the same conditions, except that one group of lines corresponds to briquets from one homogeneous sample of low-moisture briquets and the other to briquets from one homogeneous sample of high-moisture briquets. The strength is plotted against the temperature of testing (in degrees Fahrenheit) for various so-called "curing" times from one hour to seventy-two hours. On Fig. 7a is shown a typical variation of the moisture content with time after moulding, the drying being obtained by air-cooling at approximately 40° to 50°F. It appears that, for this type of briquet, after one hour (during which the moisture loss is greatest) the factor "time" (curing) is only of secondary importance and temperature is the most important factor, its influence being approximately

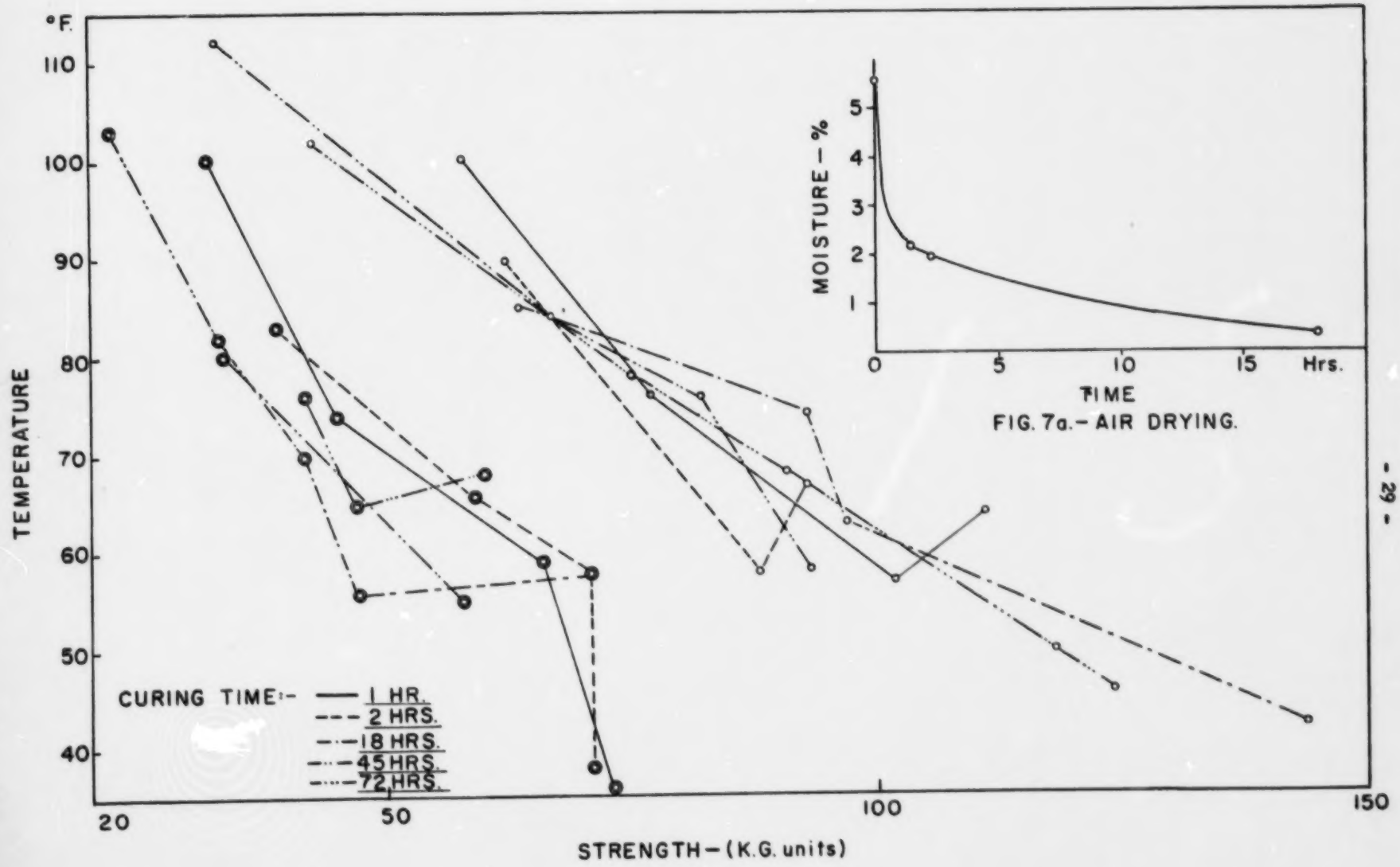


FIG. 7a. – AIR DRYING.

FIG. 7 & 7a. – STRENGTH vs. TEMPERATURE OF BRIQUET, "CURING" TIME & MOISTURE CONTENT.

Legend:- ○ —low moisture
● —high moisture

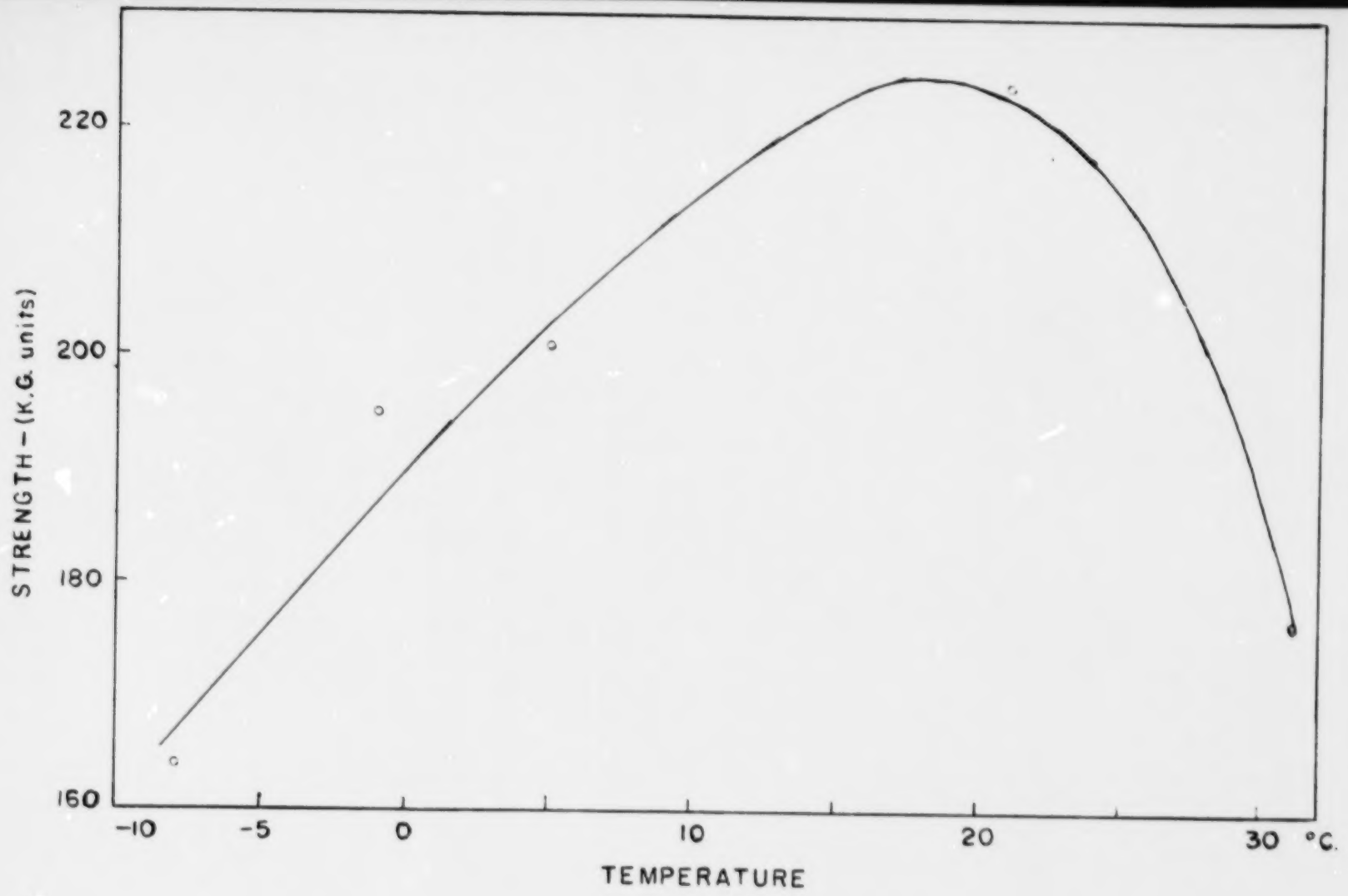


FIG. 8. – TEMPERATURE SUSCEPTIBILITY IN WINTER.

linear within a limited range of temperatures. In this case, the correction for increasing temperature could be a reduction of about one Komarek-Greaves unit per degrees Fahrenheit. It should be noted, however, that, if the moisture content varies widely over a period of time, then the concomitant influences of time and moisture content may be important.

In order to cover more fully the extensive range of temperatures observed in Canada, the influence of the testing temperature on the compressive strength is also shown on Fig. 8 for similar briquets from one homogeneous sample within the range of 31° to 8°C. below zero. In this particular case the average strength increases to a maximum near 20°C. and then decreases again when the temperature of testing is lowered further.

This may be due to a brittleness effect, certainly not to any freezing of moisture since the moisture content was extremely low in this case. It should be noted that the precision of the Komarek-Greaves tester is poor at the lower temperatures.

CONCLUSIONS

Under controlled conditions, the Komarek-Greaves compression-strength test is reliable and can be used as a dependable yardstick for evaluating the physical quality of pillow-shaped roll-press briquets made of bituminous coal and petroleum asphalt.

The suitable conditions must be determined in each case. The temperature of testing and rate of applying the load should be kept within limited ranges. Testing temperatures should be close to the average temperature that the briquets may be expected to have in practice during transportation and storage. Corrections must be made for temperature in the order of one Komarek-Greaves unit per degree Fahrenheit.

The speed of the tester should be approximately 200 r.p.m. in order

to ensure reproducible results. Results obtained at the same speed and corrected to the same arbitrary temperature can be compared for different samples of briquets with a precision which may be calculated from the standard deviation, and was, in the case of the briquets studied, approximately 3 Komarek-Greaves units for the average strength of each sub-group of 5 replicates.

Within the range of ordinary room temperatures, under summer conditions, the accuracy of the Komarek-Greaves test, as defined in this study by correlation with the instantaneous F.R.L. Test, is acceptable at higher speeds in the order of 200 r.p.m. and may be improved by suitable corrections referred to above.

The method of evaluation used in this investigation of the Komarek-Greaves tester can be applied to any test and serves as an example of how preparation engineers can study other tests such as ash determinations, sink and float computations, etc.

SECTION II

EVALUATION OF THE ASTM:D441-45 TUMBLER TEST APPLIED TO COAL BRIQUETS

APPARATUS, TESTING PROCEDURE

In this investigation, as indicated in the general introduction, the test method studied with regard to evaluating its suitability for assessing the friability of coal briquets was an adaptation of the ASTM:D441-45 Tumbler Test for Coal[1]. By this method the friability of the briquets is determined by tumbling a weighed sample of briquets without grinding media, at a fixed speed (usually 40 r.p.m.) in a porcelain or iron jar tumbler, $7\frac{1}{4}$ inches in diameter and depth, fitted with three $1\frac{1}{4}$ inch lifters, and built to the specifications of A.S.T.M. D441-45. After a given period of tumbling (usually 30 minutes) the abraded briquets are removed from the tumbler jar and screened. The weight percentage of the original briquets, retained on a relatively coarse screen (usually a one-inch-square-mesh) is termed the size "stability index" (its complement to 100 being the "friability index"), and the percentage passing through a relatively fine screen (usually 10 mesh) is termed the "abradability" or "dust index". This was the modified Tumbler Test adopted and used by the Fuels Division, Department of Mines and Technical Surveys[5] for many years.

Preliminary studies showed that the results of the Tumbler Test on coal briquets of identical quality could be affected by the following factors:

Temperature of the briquets
Duration of tumbling
Speed of rotation of the jar
Load of briquets in the jar
Number of briquets in the jar
Size of briquets
Nature of the jar, and
Gradual cushioning effect of the dust produced in the jar during the test

The effects of the various dimensions of the jar and its lifters

were not considered as this study was limited to A.S.T.M. standard equipment. The influence of size on the stability of briquets was also not studied at this time but will be the subject of a future investigation.

In order to evaluate the various influences of the above mentioned factors on the Tumbler Test with briquets of similar quality, a large and adequately homogeneous sample of typical "railway" briquets weighing approximately 3 ounces each and made of bituminous coal with about 4% asphalt, was collected from a 30 ton/hour externally tangent roll press. After storage, sub-samples of these briquets were taken at random and tested under various conditions using the ASTM:D441-45 Tumbler equipment described above. All the tests were made in three replicates; one with a porcelain jar, P, and two with iron jars, I_o and I_n.

Preliminary tests had shown that, for typical briquets made in Western Canada, the indices of stability and abradability were practically complementary, i.e. there was very little degradation material passing through the one-inch screen and retained on the 10-mesh screen, especially when the duration of tumbling was under two hours. Therefore, only the stability index was considered.

DISCUSSION OF RESULTS

Influence of the Temperature of the Briquets and of the Duration of Tumbling

In Fig. 9 are plotted the data given in Table IV, showing the stability indices obtained in the three jars at the temperatures 30.5°C., 20°C., 15°C., and -8°C., after various durations of tumbling from 5 to 180 minutes. In all cases, the speed of tumbling was 40 r.p.m. and the load was approximately 1000 grams (12 briquets).

Fig. 10 is an enlargement of Fig. 9 showing, in detail, the

TABLE IV

Stability of Railway Briquets
as Function of Temperature and Duration of Tumbling(2)

Jar type(1)	P	I_o	I_n	Average	P	I_o	I_n	Average
Temp. °C.	-8	-8	-8		15	15	15	
Initial Load - grams	1019	1011	1002	1011	1000	1000	1000	1000
Duration of Tumbling (minutes)	Stability - %							
5	93.5	95.7	95.9	95.0	95.5	96.0	96.0	95.8
10	89.5	92.4	92.2	91.4	93.0	94.0	94.0	93.7
15	85.9	88.8	89.4	88.0	91.4	91.8	91.5	91.6
20	83.1	86.7	87.1	85.6	89.8	90.3	89.9	90.0
30	77.9	78.8	83.2	80.0	86.8	87.6	86.9	87.1
45					83.8	84.4	83.6	83.9
60					80.9	82.0	80.7	81.2
90					76.6	72.4	76.2	75.1
120					70.0	65.6	72.4	69.3
150					61.2	61.0	66.5	62.9
180					55.8	57.6	60.6	58.0

Jar type(1)	P	I_o	I_n	Average	P	I_o	I_n	Average
Temp. °C.	20	20	20		30.5	30.5	30.5	
Initial Load - grams	981	981	997	986	969	977	961	969
Duration of Tumbling (minutes)	Stability - %							
5	95.0	94.9	95.1	95.0	98.2	98.1	98.4	98.2
10	94.7	94.5	95.0	94.7	96.5	95.6	96.9	96.6
15	93.2	93.2	93.5	93.3	95.4	95.3	95.6	95.4
20	91.9	92.2	91.9	92.0	94.0	94.6	94.7	94.4
30	89.1	89.4	89.9	89.5	92.2	92.2	92.0	92.1
45	86.3	86.8	87.1	86.7	89.4	90.0	88.6	89.3
60	83.8	84.4	84.6	84.3	87.3	87.8	86.2	87.1
90	80.3	80.0	80.7	80.3	83.0	84.1	81.6	82.9
120	76.8	72.4	77.4	75.5	79.6	78.1	73.9	77.2
150	-	-	-	-	-	-	-	-
180	67.3	64.4	69.6	67.1	70.8	70.1	66.2	69.0

(1) P = Porcelain I_o and I_n = Iron

(2) Tumbling speed - 40 r.p.m.; Load - 12 briquets

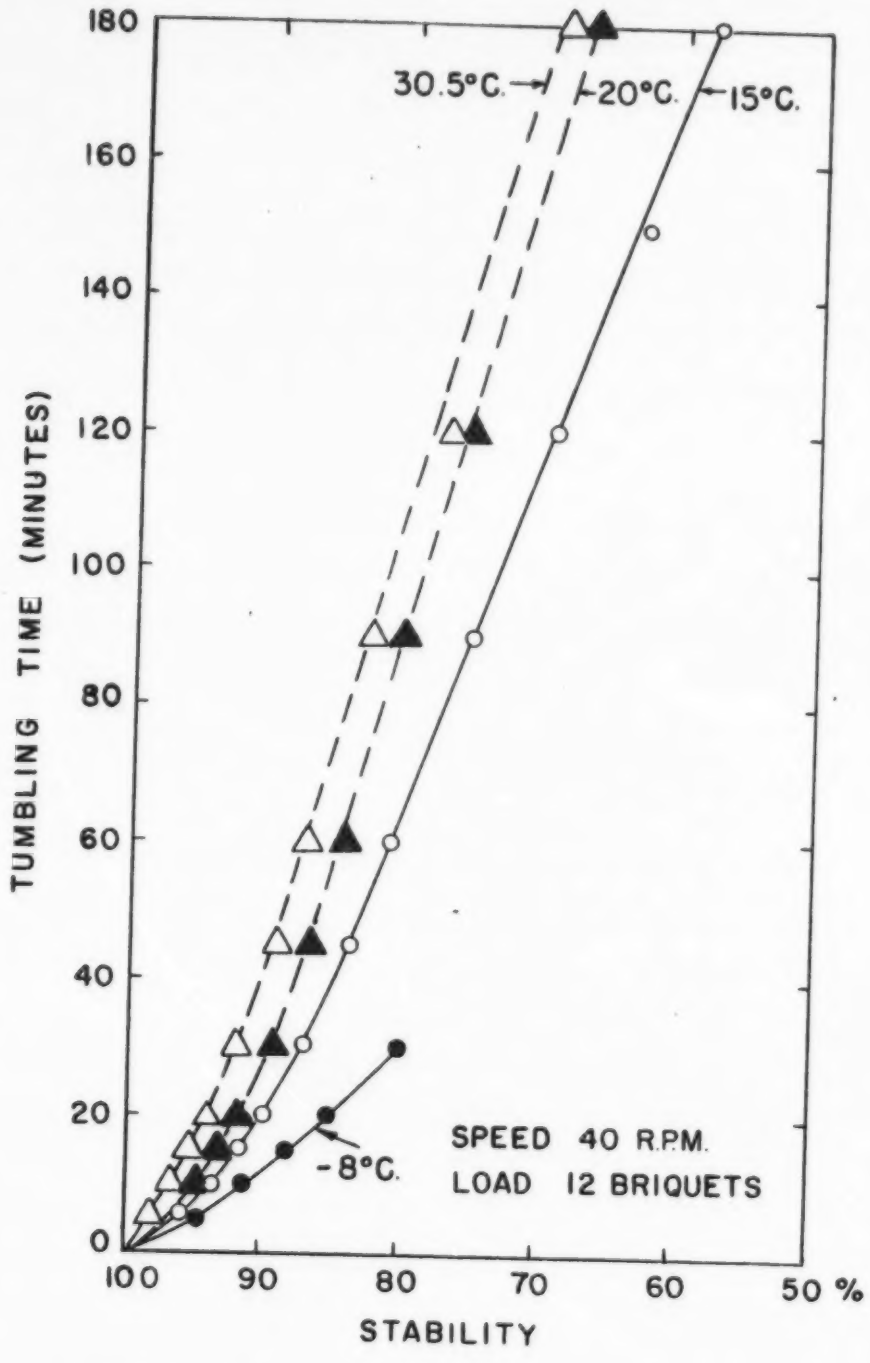


FIG. 9.— STABILITY vs. TUMBLING TIME AND TEMPERATURE.

variations of stability corresponding to tumbling times up to 45 minutes. It is apparent that the rate of degradation (i.e. the slope of the isotherms) is fairly constant after the first 15 to 20 minutes, when the shape of the briquets has changed from the original pillow-shape to an approximate ellipsoid or even a sphere. This rate of degradation appears to be independent of any fins or rough edges existing in the original briquets. Therefore, it would seem that the tumbling time could be reduced to 15 to 20 minutes without disadvantage.

Similar results were obtained when comparing briquets of different qualities[13].

Fig. 11 is another presentation of the same data, showing the variations of stability with temperature after various tumbling times.

It is clear that abrasion is greatly reduced when the temperature of the briquets is raised from -8° to 30.5°C. The temperature susceptibility is even more pronounced for longer tumbling times, thereby showing a certain interaction of temperature and tumbling time.

To a large extent, changing the temperatures of the briquets being tested is equivalent to testing briquets with a different resistance to abrasion. Since sensitivity (i.e. the responsiveness to slight changes in quality) is a desirable characteristic of this test for comparison of various briquets, it seems that tumbler tests would be more valuable if conducted at lower temperatures, thereby obtaining greater sensitivity. However, as shown in Fig. 10, the dispersion of replicate tests is much worse at lower temperatures, and, in the case of the briquets studied, the optimum temperature would be 15° to 20°C. When comparing briquets tested at different temperatures the stability indices should be corrected to an

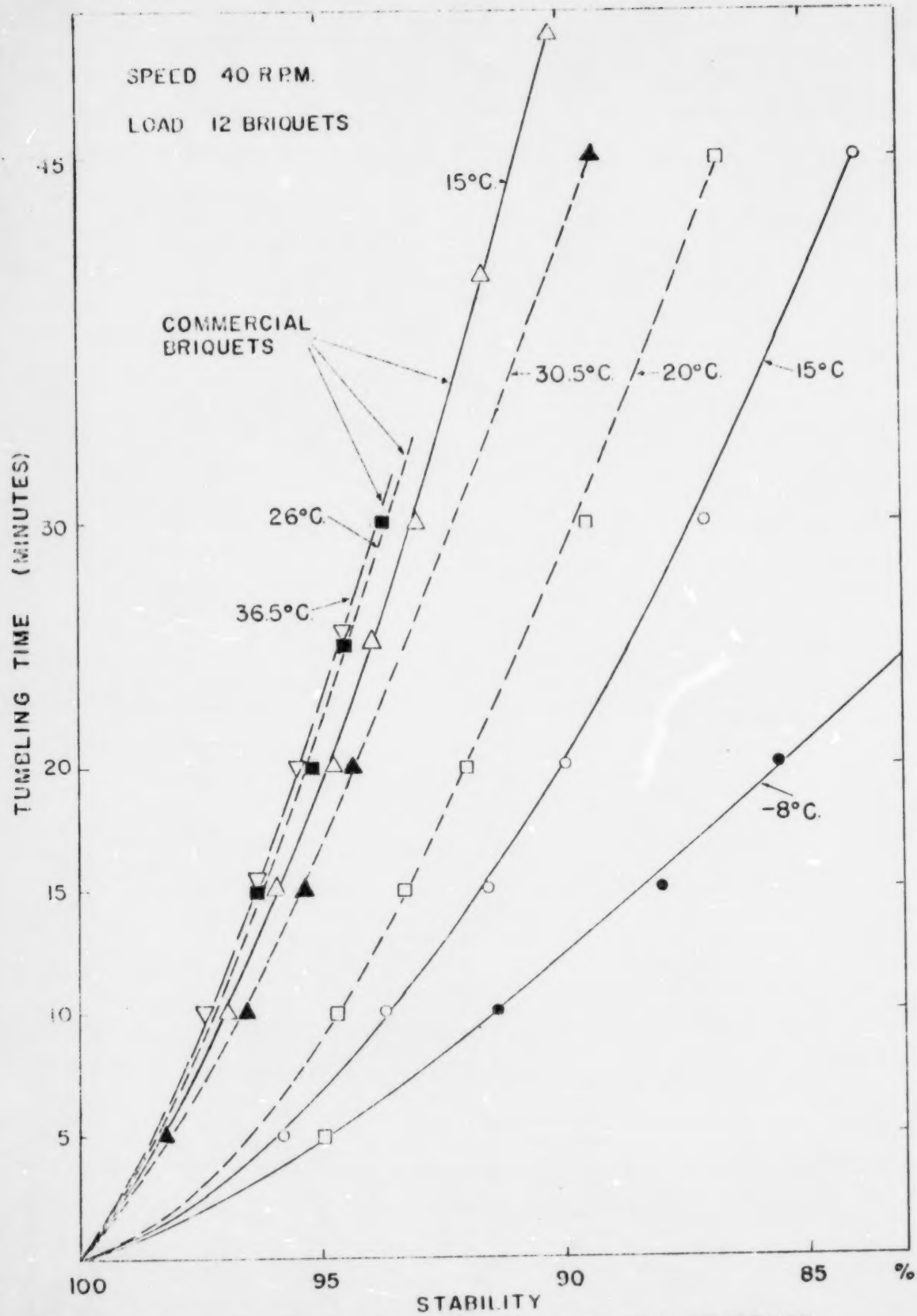


FIG.10.– STABILITY vs. TUMBLING TIME, TEMPERATURE

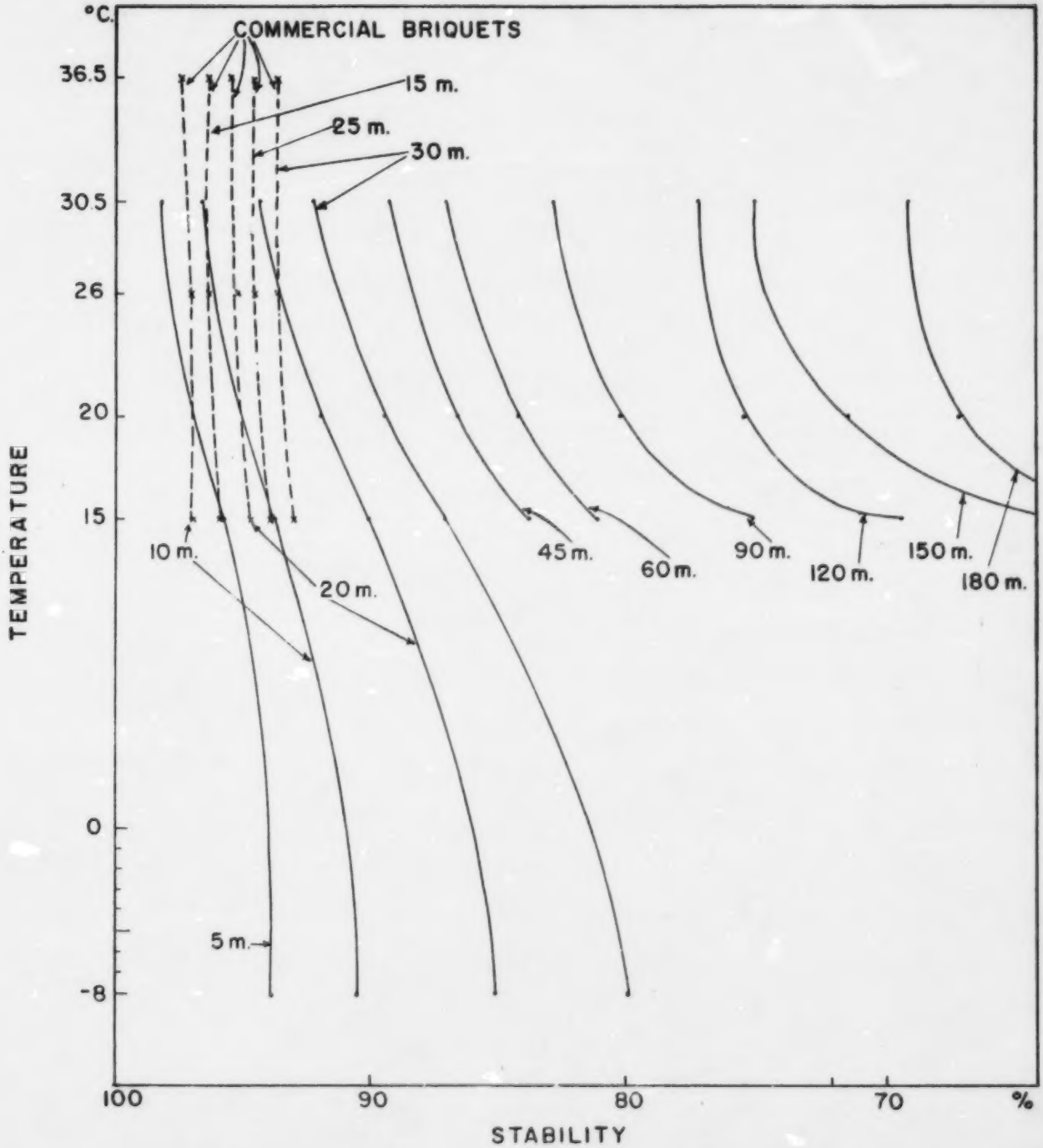


FIG. II.– STABILITY vs. TEMPERATURE AFTER VARIOUS TUMBLING TIMES. (in Minutes–m.)

arbitrarily fixed temperature by linear interpolation such as may be based on Fig. 11, by assimilating the isochronous curves to straight lines within limited ranges of temperatures.

Influence of Speed of Tumbling

In Fig. 12 are plotted, after correction for temperature, the data given in Table V, showing the stability indices obtained in the three jars rotated at 20, 40, 61 and 86 r.p.m. after various tumbling times from 10 to 60 minutes. In all cases, the load (12 briquets) was approximately 1000 grams and the stability indices were corrected (by linear interpolation) to a constant temperature of 20°C.

Fig. 13 is another presentation of the same data, showing the variations of the stability index with the speed of rotation after various tumbling times. It appears that the abradability index and the rate of degradation increase as speed increased from 20 r.p.m. up to a maximum of abrasion for speeds approximately 60 r.p.m., and then decrease as the increasing centrifugal forces tend to hold the briquets against the jar wall. The optimum speed of rotation of the tumbler in this case seems to be about 60 r.p.m., as the rate of degradation is then maximum and the tangents to the isochronous curves of Fig. 13 are vertical, so that the variation of stability with speed of tumbling is minimum. However, the dispersion of replicate tests is least at 60 r.p.m.

TABLE V

Stability vs. Speed and Duration of Tumbling
(Railway Briquets)

Tumbling Speed:R.P.M.	20				40			
Temp. °C.	20				20			
Jar type(1)	P	I_o	I_n	Aver-age	P	I_o	I_n	Aver-age
Initial Load - grams	957	952	955	955	981	927	997	968
Tumbling Time (minutes)	Stability - %							
10	-	-	-	-	94.7	94.5	95.0	94.7
15	96.4	97.2	97.5	97.0	93.2	93.2	93.5	93.3
20	-	-	-	-	91.9	92.2	91.9	92.0
25	-	-	-	-	-	-	-	-
30	94.1	95.0	95.3	94.8	89.1	89.4	89.9	89.5
40	92.5	93.4	94.0	93.3	-	-	-	-
45	-	-	-	-	86.3	86.8	87.1	86.7
50	91.0	92.2	92.6	91.9	-	-	-	-
60	89.4	90.9	91.5	90.6	83.8	84.4	84.6	84.3

Tumbling Speed:R.P.M.	61				86			
Temp. °C.	24				23			
Jar type(1)	P	I_o	I_n	Aver-age	P	I_o	I_n	Aver-age
Initial Load - grams	971	965	960	965	958	958	957	958
Tumbling Time (minutes)	Stability - %							
10	94.3	95.3	95.4	95.0	94.8	95.6	95.8	95.4
15	92.4	93.9	93.8	93.4	93.2	94.2	94.7	94.0
20	-	-	-	-	-	-	-	-
25	88.7	90.5	90.9	90.0	90.1	91.8	92.2	91.4

(1) P = Porcelain I_o and I_n = Iron

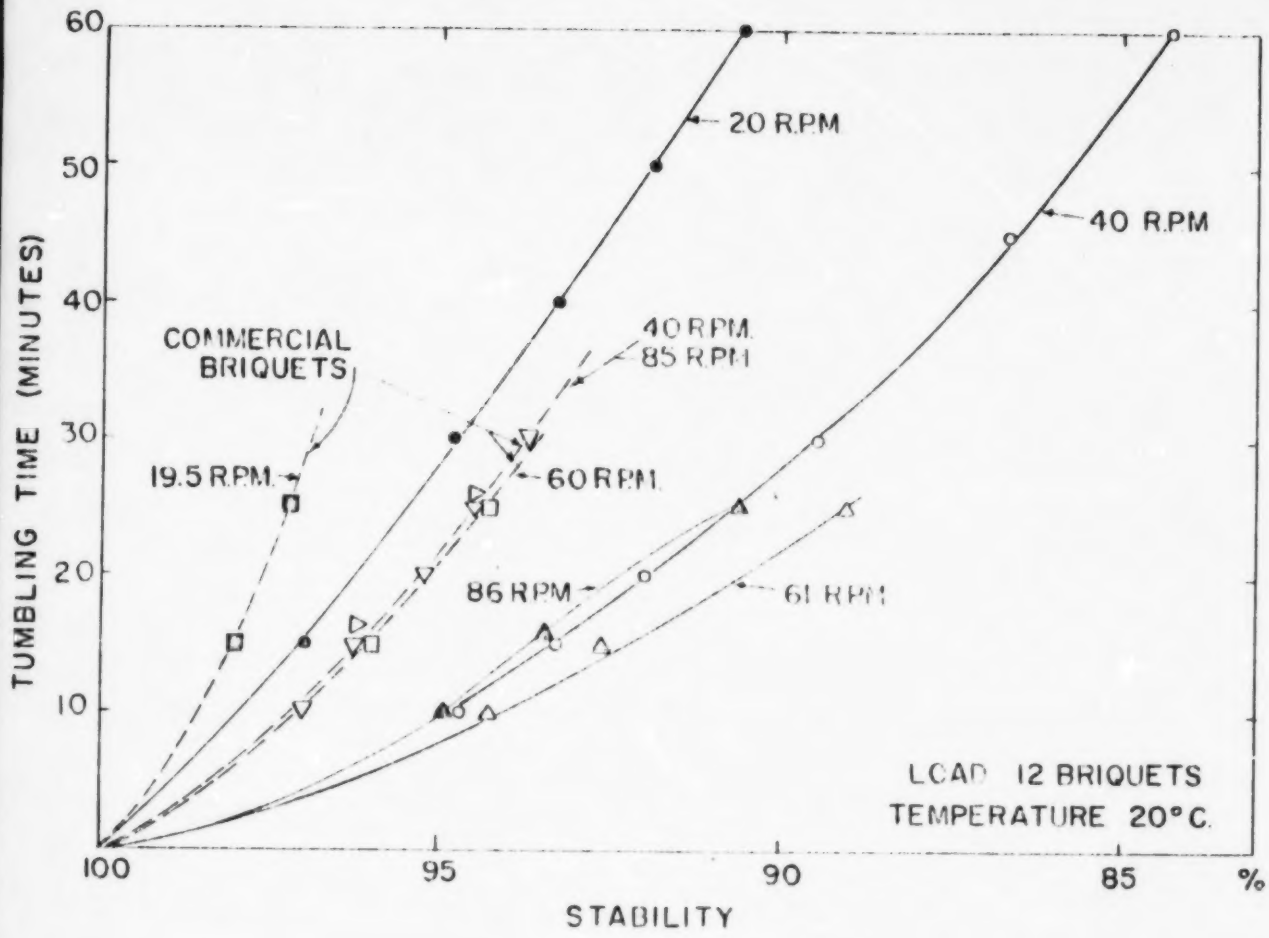


FIG.12.- STABILITY vs TUMBLING TIME AT VARIOUS SPEEDS OF TUMBLING

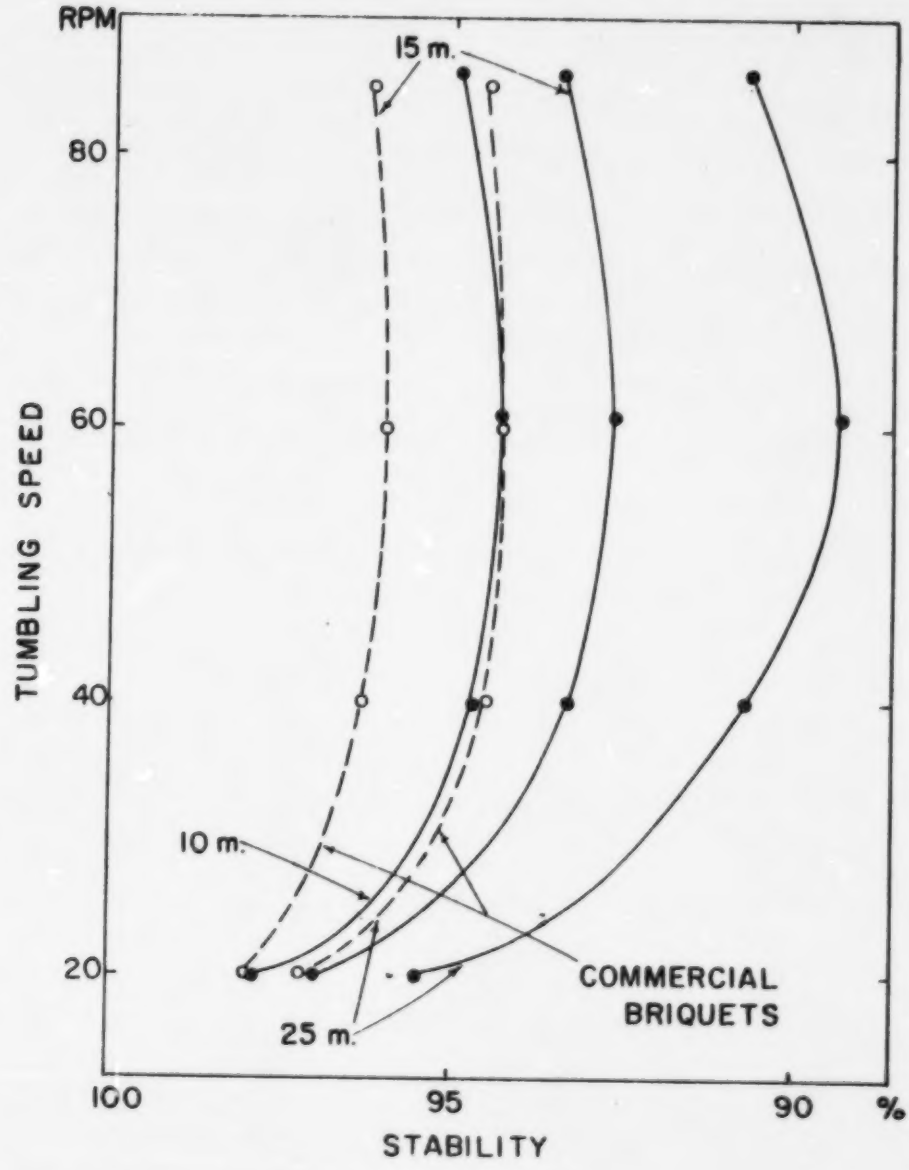


FIG. 13 — STABILITY vs. TUMBLING SPEED AFTER VARIOUS TUMBLING TIMES (MINUTES m.)

Influence of the Load and Number of Briquets in the Tumbler Jar

In Fig. 14 are plotted the data of Table VI, giving the stability indices obtained in the three jars after 15 and 25 minutes of tumbling for various initial numbers of briquets from 4 to 24. In all cases, the speed of rotation was 40 r.p.m., and the stability indices were corrected (by linear interpolation) to a constant temperature of 20°C.

Fig. 15 is another presentation of the same data, showing the variations of the rate of degradation with the number of briquets being tumbled. In Fig. 16 are plotted the same data, showing the variations of the stability indices with the initial load of briquets placed in the tumbler jars.

When tumbling coal, Yancey and his associates[14] used a load of 1000 grams rather than the 1200 grams originally specified by the Canadian Fuels Research Laboratories, and the A.S.T.M. standard for coal tumbling specifies a sample of 1000 grams in each of at least four replicate jars. This weight was adopted by the Fuels Division in the past for tumbling coal briquets but some investigators have taken as little as three briquets[4].

The data, presented above, indicates that the sensitivity of the test is improved by using a smaller number of briquets, thereby producing more abrasion. When the number of briquets is in the range of 4 to 16, variation of stability with number is approximately linear as shown in Fig. 14 and, contrary to what would be expected, the dispersion of replicate tests is not worse with a smaller number of briquets. The rate of degradation is considerably increased when the number of briquets being tumbled is reduced. Generally, it would appear that a standard calling for approximately twelve 2 to 3-ounce briquets, giving a load of about 1000 grams, is satisfactory.

TABLE VI

Stability vs. Number and Load of Briquets in Jar
(Railway Briquets - Tumbling Speed: 40 R.P.M.)

Temp. °C.	23				20				19.8				19.0				20			
Number of Briquets	4				6				8				10				12			
Jar type	P	I_o	I_n	Aver-age	P	I_o	I_n	Aver-age	P	I_o	I_n	Aver-age	P	I_o	I_n	Aver-age	P	I_o	I_n	Aver-age
Initial Load - grams	328	324	323	325	483	485	486	485	646	654	646	649	818	822	814	818	981	981	997	986
Tumbling time in minutes	Stability - %																			
15	90.5	91.0	90.1	90.5	90.7	91.1	92.8	91.5	91.8	92.2	92.7	92.2	92.9	93.4	94.3	93.5	93.2	93.2	93.5	93.3
25	86.0	85.2	86.1	85.8	85.7	86.4	88.5	86.9	87.2	88.5	89.3	88.3	90.0	89.8	91.0	90.3	-	-	-	-
30													-	-	-	-	89.1	89.4	89.9	89.5

Temp. °C.	21				21				19.2				21.0				21.0			
Number of Briquets	14				16				20				22				24			
Jar type	P	I_o	I_n	Aver-age	P	I_o	I_n	Aver-age	P	I_o	I_n	Aver-age	P	I_o	I_n	Aver-age	P	I_o	I_n	Aver-age
Initial Load - grams	1134	1147	1141	1141	1295	1297	1306	1299	1612	1610	1635	1619	1784	1785	1795	1788	1925	1931	1920	1925
Tumbling time in minutes	Stability - %																			
15	94.4	95.6	96.2	95.4	96.1	97.0	97.3	96.8	97.3	97.8	98.2	97.8	98.0	98.4	98.6	98.3	98.7	99.0	99.1	98.9
25	92.0	93.5	94.5	93.3	93.8	95.2	95.7	94.9	96.0	97.1	97.5	96.9	97.0	97.9	97.8	97.6	97.8	98.6	98.5	98.3

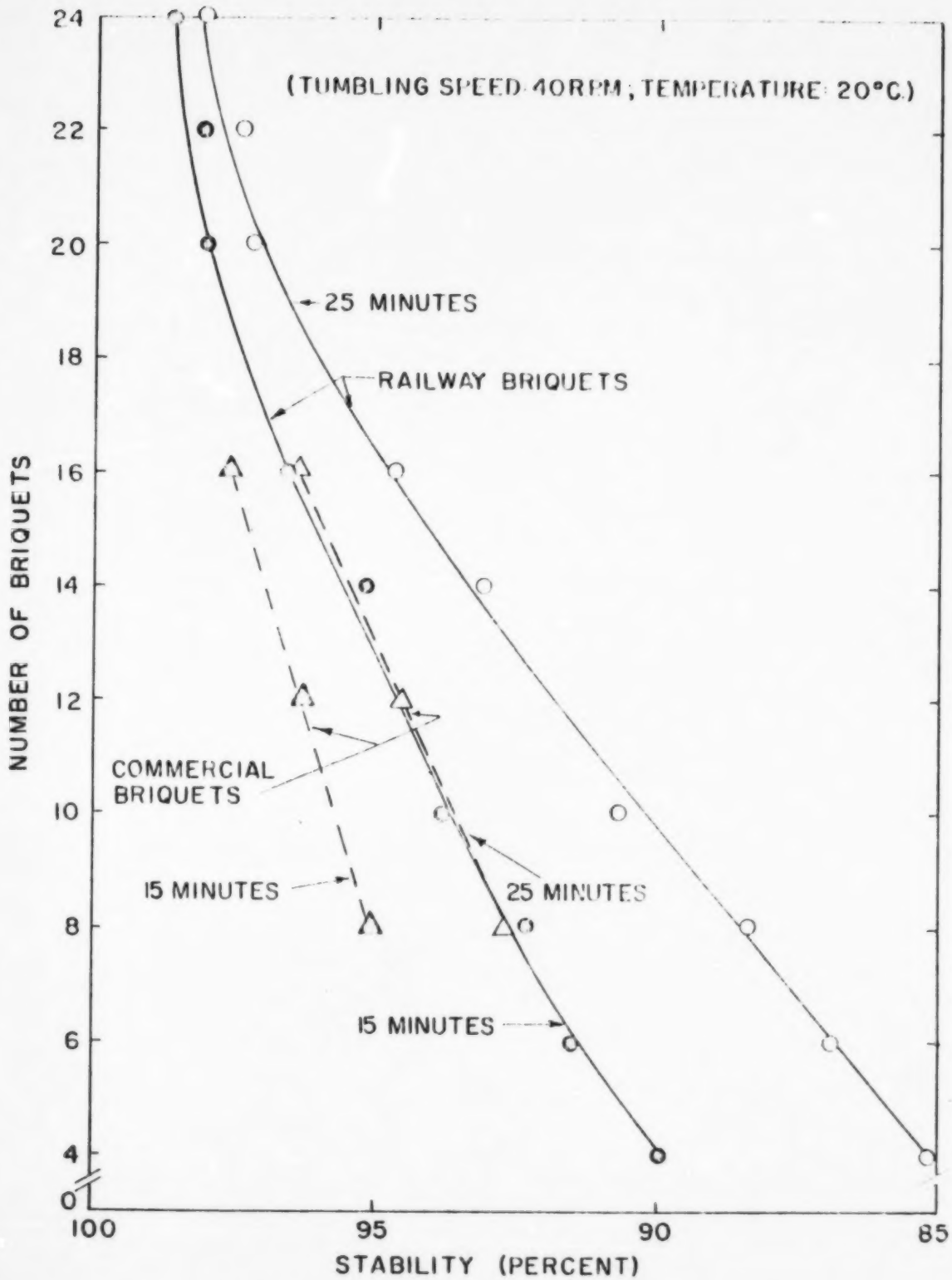


FIG.14.– STABILITY vs. NUMBER OF BRIQUETS.

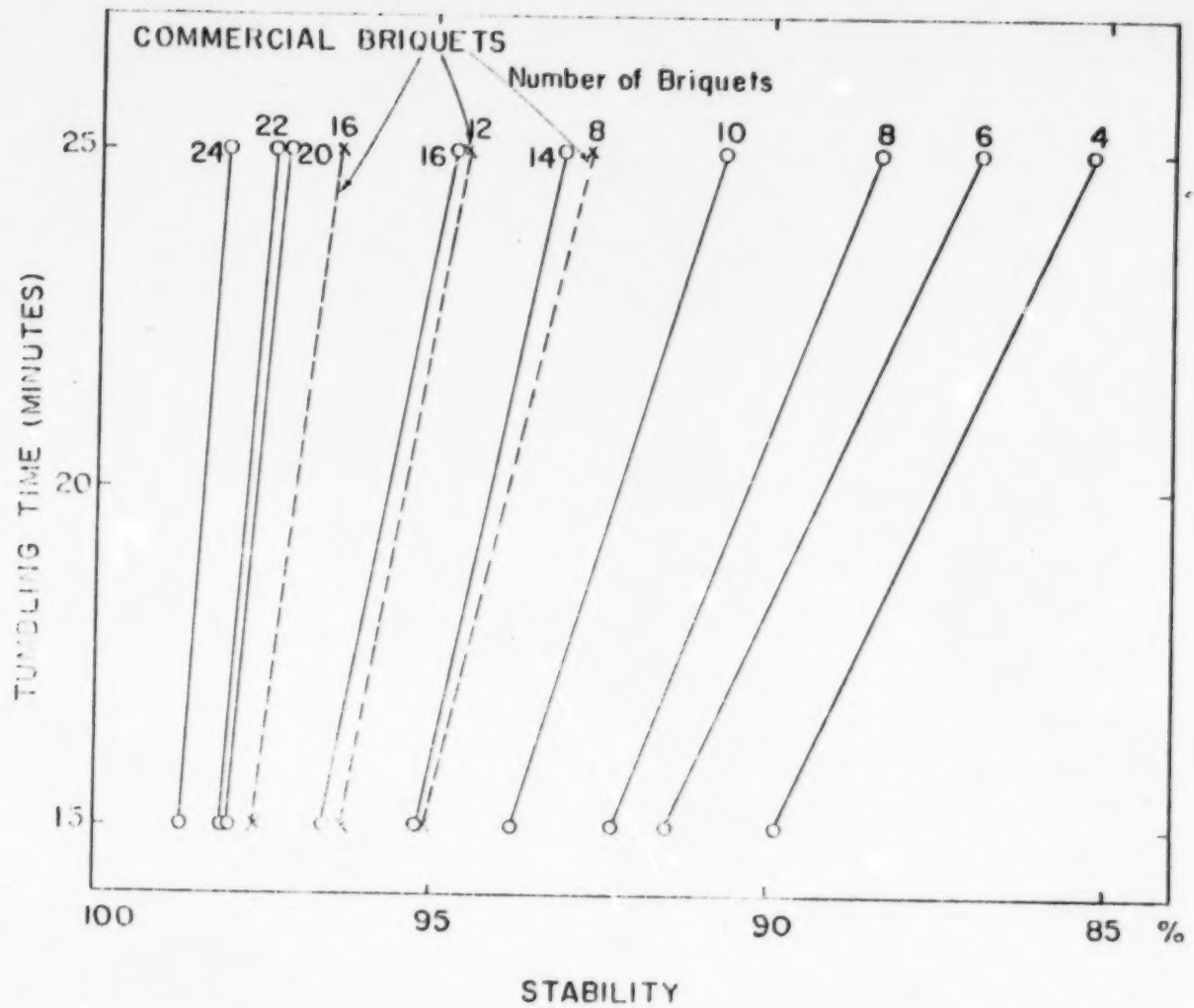


FIG. 15 – STABILITY vs. TUMBLING TIME WITH VARIOUS NUMBERS OF BRIQUETS IN THE TUMBLER JAR.

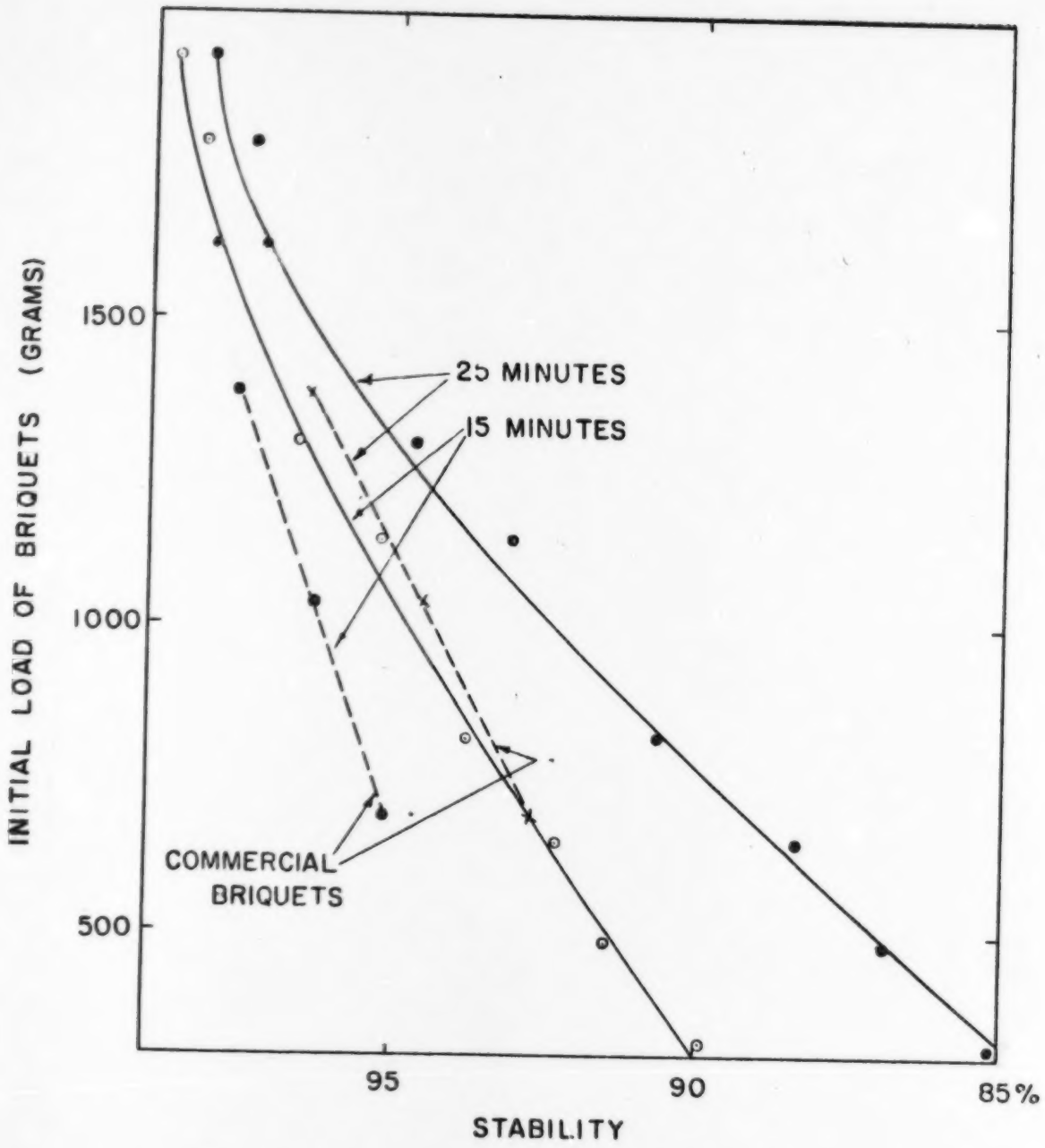


FIG. 16.—STABILITY vs. LOAD OF BRIQUETS.

Usually, when comparing the friability of briquets of different sizes, the same load (often close to 1000 grams) is used for tumbler tests on all types of briquets. Thus, a larger number of briquets of the smaller size will be required to have the same load under test.

The influence of size on the stability of briquets was not studied in this investigation, but it is proposed to undertake comparative tests of a stoker-size and 2½-ounce briquets (made simultaneously with the mix from the same fluxer) which will be separately reported.

Other Factors Concerning Stability

Type of Jar

It is apparent from the data obtained in this study that porcelain and iron jars give very similar values for the stability factors although a number of tests tended to show a little more abrasion in the porcelain jar. With the type of briquets considered in this investigation, the difference was not regarded as being of sufficient magnitude or consistency to warrant special attention, when the other factors are preponderant.

Dust Removal during Tumbling

Other tests not recorded in this report showed that the frequent removal of dust from the jar seems to have very little effect on stability, with tumbling times up to 30 minutes under ordinary testing conditions. "Sweetening" or removal of the dust and its replacement by fresh material was not studied here in view of its impracticability under operational conditions.

Quality of Briquets

Finally, the quality of the briquets was considered and a number of tumbler tests were conducted on similar types of briquets of "commercial" quality containing about 6% asphalt. At 25°C. these tested higher than 400 on the Komarek-Greaves compression-strength tester, as compared to average values of 200 for the "railway" briquets mentioned above. The corresponding data are given in Table VII and plotted on Fig's. 10 to 16 inclusive.

CONCLUSIONS

The A.S.T.M. D-441-45 Tumbler Test for coal may be adapted to briquets made of bituminous coal and asphalt in externally tangent roll presses producing pillow-shaped briquets of 2 or 3 ounces. This test is reliable under the following optimum conditions:

Constant speed of tumbling: in the order of 40 to 60 r.p.m.

Constant number of briquets: in the order of 12.

The stability index may be defined as the percentage of the original weight retained on a one-inch-square-mesh screen after 15 minutes at an arbitrary, constant temperature in the order of 20°C. If the temperature, the duration, the load, or the speed of tumbling are different when comparing the qualities of different briquets, corrections should be made on the assumption that the variations of stability due to these factors are linear within a limited range. In particular, the results should be corrected to an arbitrary temperature close to the average temperature, which the briquets may be expected to have during transportation.

TABLE VII

Stability of Commercial Briquets

Tumbling Speed: R.P.M.	40				40				40				40			
Temp. °C.	26				26				25.5				36.5			
Number of Briquets	8				12				16				12			
Jar type	P	I_o	I_n	Average	P	I_o	I_n	Average	P	I_o	I_n	Average	P	I_o	I_n	Average
Initial Load - grams	693	688	688	690	1047	1038	1030	1038	1381	1376	1388	1382	1041	1033	1042	1039
					Stability - %											
Tumbling time in minutes 10					96.4	96.9	97.7	97.0					97.0	97.2	97.9	97.4
15	95.1	95.1	95.1	95.1	95.9	96.1	96.8	96.3	97.0	97.7	98.1	97.6	96.0	96.2	96.8	96.3
20					94.4	95.2	96.0	95.2					95.0	95.3	96.0	95.4
25	92.8	92.7	92.7	92.7	94.0	94.6	95.0	94.5	96.2	96.8	97.4	96.4	94.0	93.8	95.8	94.5
30					92.8	93.8	94.5	93.7					93.3	92.8	94.8	93.6

Tumbling Speed: R.P.M.	19.5				60				85				40			
Temp. °C.	28				27				26.5				15			
Number of Briquets	12				12				12				12			
Jar type	P	I_o	I_n	Average	P	I_o	I_n	Average	P	I_o	I_n	Average	P	I_o	I_n	Average
Initial Load - grams	1029	1030	1034	1031	1034	1042	1032	1036	1028	1028	1034	1030	1039	1039	1024	1034
					Stability - %											
Tumbling time in minutes 10									-	-	-	-	96.5	97.0	97.1	96.9
15	97.8	98.0	98.2	98.0	95.9	96.2	95.8	96.0	96.2	95.9	96.4	96.2	95.9	95.7	96.0	95.9
20	-	-	-	-	-	-	-	-	-	-	-	-	94.7	94.3	95.1	94.7
25	96.9	97.3	97.3	97.2	93.9	94.4	94.6	94.3	94.9	94.0	94.5	94.5	93.9	93.2	94.5	93.9
30													93.6	92.0	93.4	93.0
40													91.8	90.5	92.6	91.6
50													90.9	88.6	91.2	90.2
60													90.3	86.6	90.6	89.2

Alternatively, the Tumbler Test could be characterized by the rate of degradation of the briquets after 15 to 20 minutes of tumbling.

Under these well-controlled conditions with the typical briquets tested, three replicates seem to be sufficient, at ordinary room temperatures, to give an adequate precision, which may be calculated from the standard deviation of the average stability of the three replicates. Here, it was in the order of three units of stability.

It is hoped that this study may be helpful in establishing acceptable standards of tumbler testing for coal briquets.

SECTION III

CORRELATION OF THE TUMBLER TEST AND THE COMPRESSION-STRENGTH TEST

Fig. 17, (Table VIII), shows a correlation of the tumbler test with the corresponding values obtained with the same samples of briquets on the Komarek-Greaves compression strength tester[12]. It appears that the tumbler test may not be as sensitive to changes in the quality of briquets as the compression-strength test. For purposes of comparison, Fig. 18 shows a correlation of the resistance to crushing (in kg/cm^2) with the cohesion index, i.e. the percentage of original material retained on a 4 mm. square-mesh screen after three cylindrical briquets of 2-inch diameter and 1-inch height were tumbled in a drum of approximately 20-inch diameter and 6-inch height for $\frac{1}{2}$ hour at 40 r.p.m. These tests, reported by Audibert and Raineau[15], were conducted on briquets made of bituminous coals with coal-tar pitch as the binder. Similar results are presented in Fig. 19, where a correlation is shown of the transverse breaking strength with the ASTM:D441-45 Tumbler Test (60 r.p.m., 40 minutes). In this case, five specimens, $1\frac{1}{4}$ inches in diameter and $1\frac{1}{4}$ inches in length, of carbonized briquets of anthrafines and bituminous binders, were tumbled together in each test[16].

All these tests show a similar relationship between compression strength and tumbler stability for testing temperatures in the range of 10^o - 20^oC. In the case of briquets bound with coal-tar pitch, the cohesion at ordinary temperatures appears to be a simple concomitant function[17] (rather insensitive) of the resistance to crushing, but with asphalts this relationship may be valid only within a limited range of temperatures. In order to indicate the relationship of the tumbler stability and the compression strength at various temperatures, Fig. 20 shows a correlation of these two characteristics at 32^o, 77^o, and 100^oF,

TABLE VIII

Correlation of A.S.T.M.: D 441-45 Tumbler Test with Komarek-Greaves Compression Test

Tumbler Test*		Compression Test
Abradability %	Stability %	K-G. Units
14.6	85.4	73
22.5	77.5	31
12.1	87.9	91
17.2	82.8	49
12.0	88.0	96
13.7	86.3	55
10.6	89.4	117
14.2	85.8	122
16.2	83.8	88
31.5	68.5	26
12.1	87.9	111
20.1	79.9	47
11.8	88.2	97
19.3	80.7	89
8.8	91.3	123
17.5	82.5	36
9.2	90.8	178
11.5	88.5	78
10.8	89.2	206
18.3	81.7	129
11.0	89.0	151
17.6	82.4	67
9.2	90.8	159
13.2	86.8	105
8.4	91.6	125
17.0	83.0	60
7.8	92.2	169
13.0	87.0	114
6.0	94.0	141
8.3	91.7	123
6.0	94.0	143
8.7	91.3	137

* 20 minutes tumbling at 40 r.p.m.

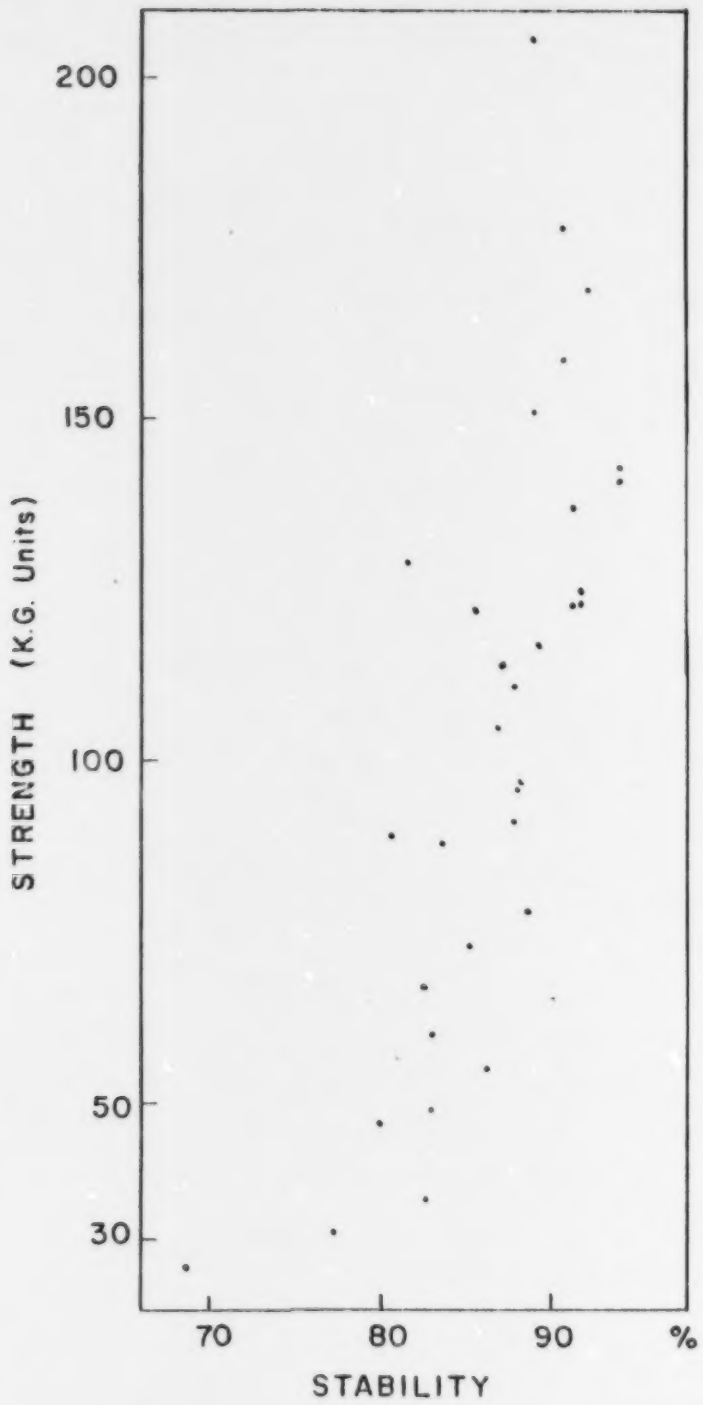


FIG. 17 – CORRELATION OF TUMBLER AND COMPRESSION TESTS.

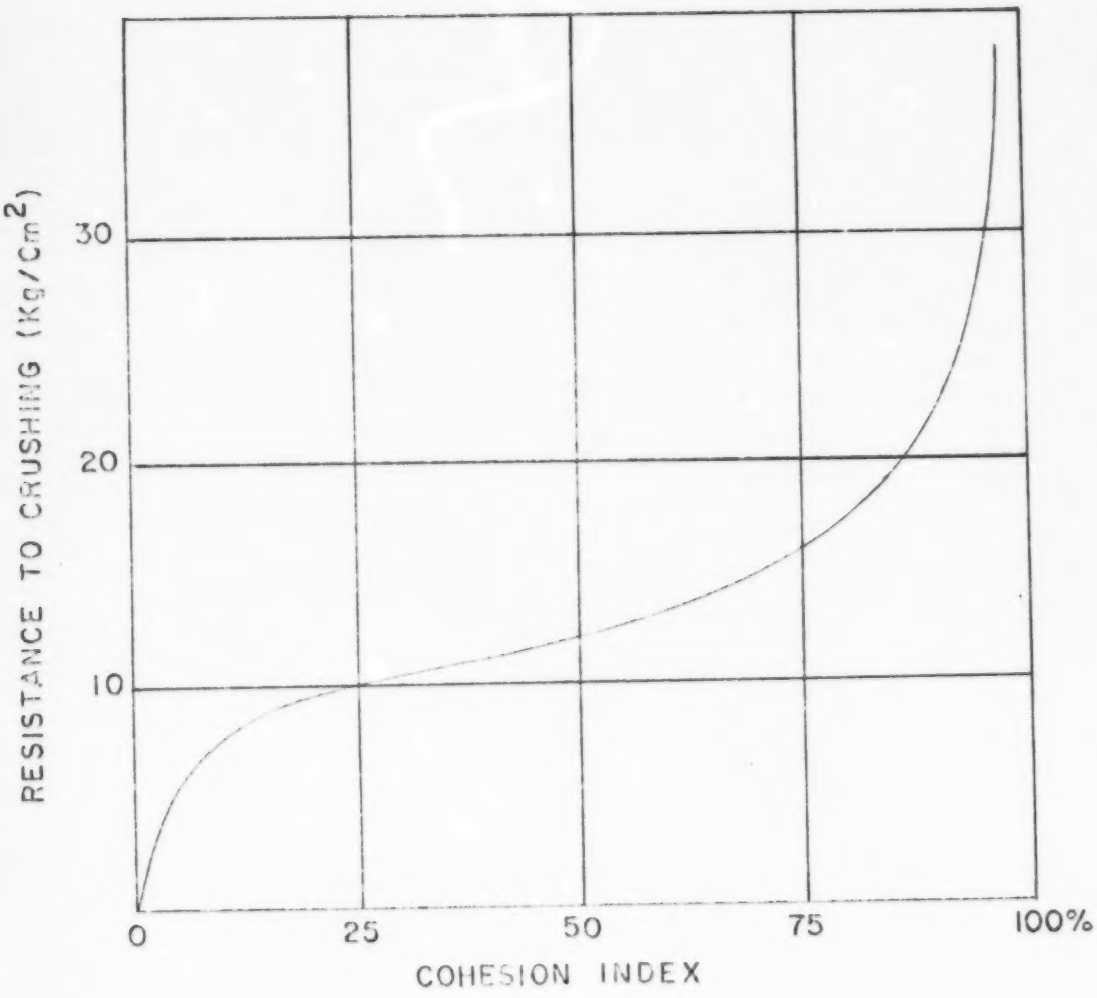


FIG.18.- CORRELATION OF COHESION AND CRUSHING TESTS.

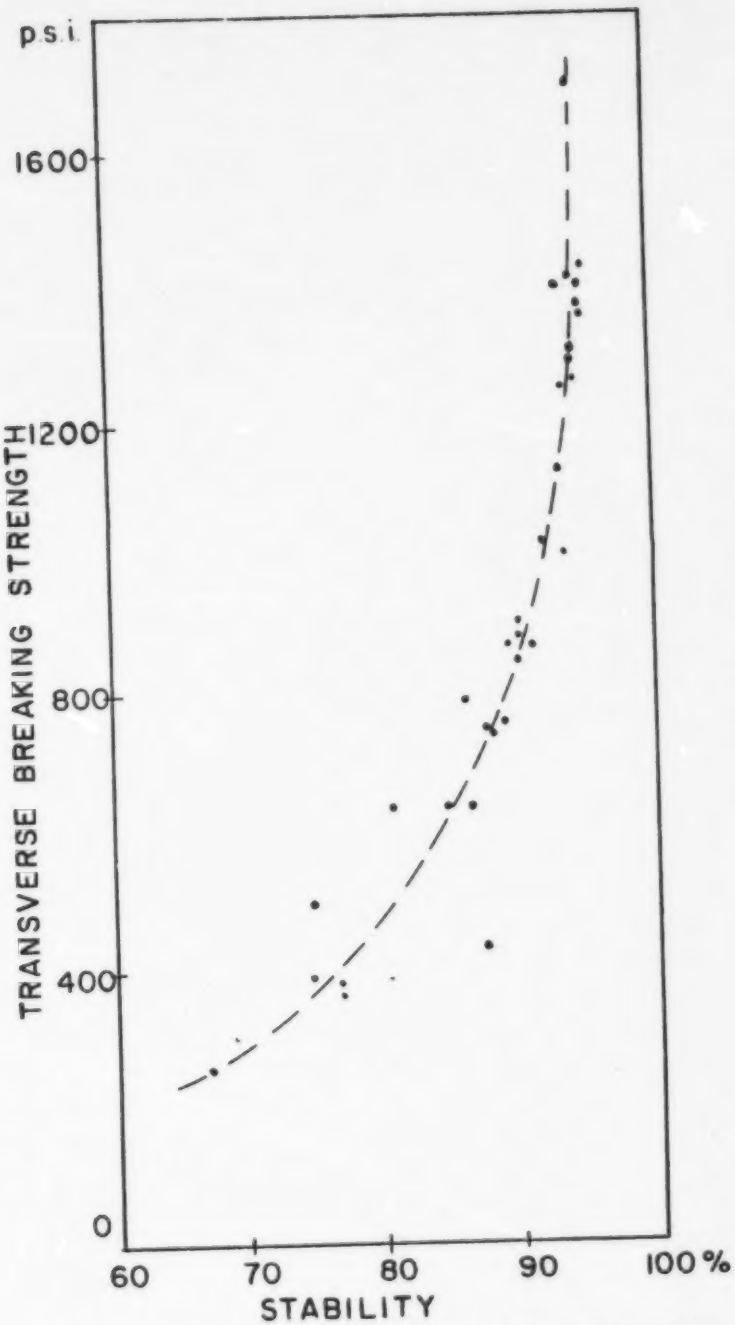


FIG. 19.- CORRELATION OF TUMBLER AND STRENGTH TESTS.

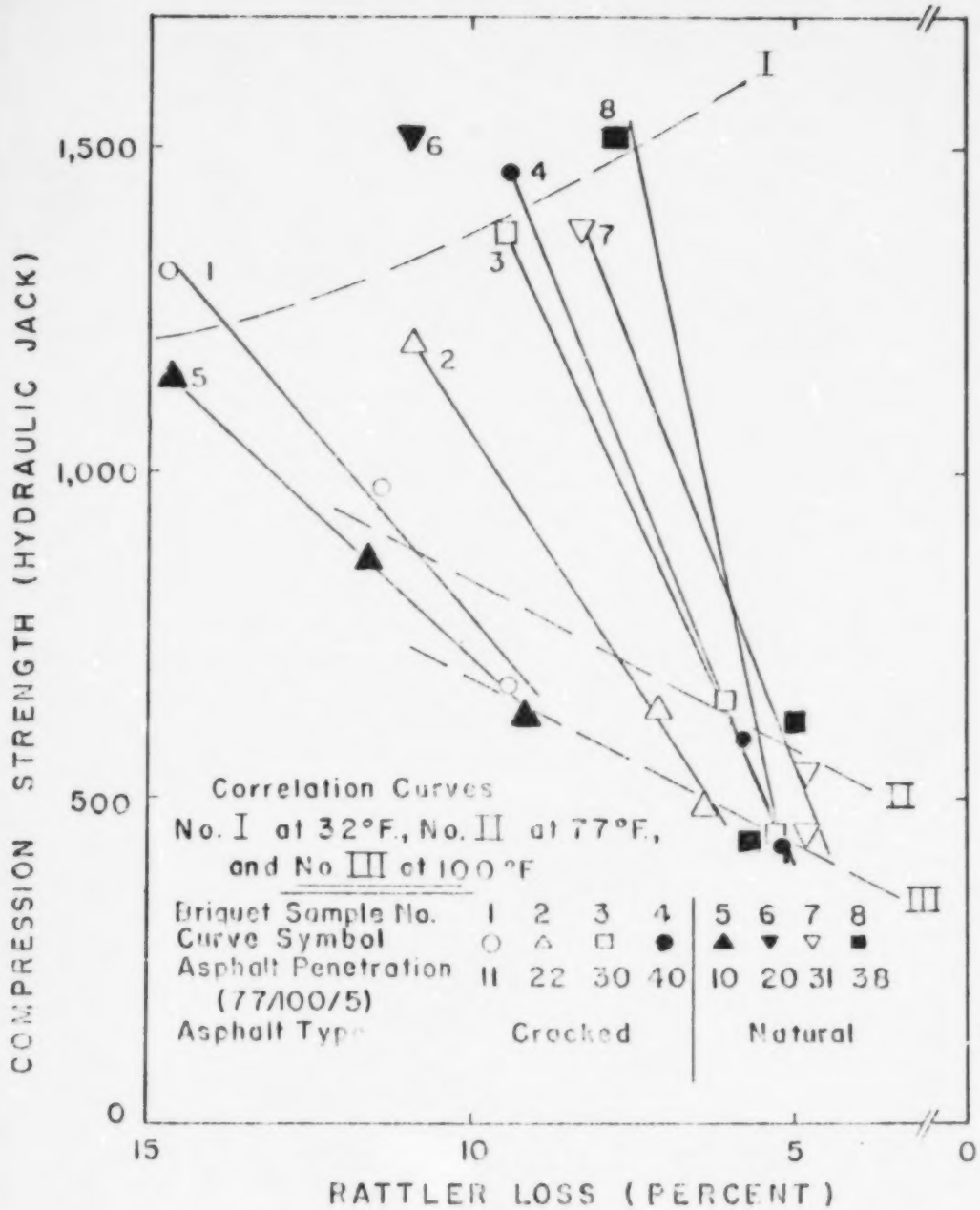


FIG. 20.— CORRELATION OF COMPRESSION STRENGTH WITH ABRASION RATTLER TEST LOSS AT 32°F., 77°F., AND 100°F. FOR BRIQUETS MADE WITH EIGHT DIFFERENT ASPHALTS (M.R. 6)

for eight different samples of briquets made with eight different asphalts(11) at the Research Council of Alberta. The Rattler Loss, used as the criterion of friability in this case, is the percentage loss in weight from the original load of 2000 grams, through the slots of a rattler drum (A.S.T.M. Tumbler Test for Bricks) of 30-inch diameter, 25-inch length, rated at 32 r.p.m. for 200 revolutions. At 32°F. the isotherm correlation curve is similar to those of Fig's. 17, 18 and 19. At this temperature, a high value of compression strength seems to ensure a high value of rattler stability, and the compression test is to be preferred as more practical. Thus, under winter conditions, the Tumbler Test may be omitted, since, when comparing two types of briquets, a higher compression strength will guarantee a higher resistance to abrasion. It follows that a minimum standard of acceptable strength may be established, which will ensure that the two main physical qualities (strength and stability) will be above satisfactory minimum levels.

On the contrary, in the range of temperatures from 77° to 100°F. corresponding to summer conditions, the two correlation curves of Fig. 20 have negative slopes, and standards of acceptable physical qualities for briquets should be based on a compromise, since high strength is then accompanied by low abrasion stability and vice versa. Under these conditions, the Tumbler Test cannot be dispensed with, unless the standards of strength are defined by two acceptable limits:

A minimum strength to ensure sufficient resistance to crushing, and

A maximum strength to ensure adequate resistance to abrasion.

Any such standards of physical quality should, of course, be different for each type of briquet as these would be affected by the type

and proportion of the asphalt used as binder, the characteristics of the coal and briquetting process, and the levels of qualities desired in relation to the corresponding variations in costs of briquetting.

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